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Population Ecology of Vertebrates in Undisturbed and Rehabilitated Habitats on the Northern Sandplain of Western Australia

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Summary

1. This study compared vegetation and vertebrate fauna within two rehabilitated and three undisturbed locations at the Renison Goldfields Consolidated (RGC) Mineral Sands minesite near Eneabba. Bi-monthly surveys were conducted between July 1987 and September 1988 Vertebrate species diversity and population dynamics, and the abundance and flowering phenology of major nectar-producing plant species were monitored at each site.

2. The three undisturbed sites chosen were representative of the major vegetation associations that occur within the Eneabba tenements of RGC. These were identified as: Site 1, comprising heath on lateritic sand and gravel, and with the highest plant species diversity of all sites; Site 4, having heath on sand ridges or dunes, with the greatest plant density of all sites; and Site 5, comprising heath on winter-wet depressions that provided the greatest canopy cover. Prior to mining, the rehabilitated sites (Sites 2 and 3) had supported heaths on lateritic sand and gravel that were similar to those at Site 1. At the time of this study, Site 2 (five years post-mining) had low canopy cover, although its plant density and species diversity approached those of Site 1; Site 3 (ten years post-mining) had the lowest plant density, species diversity and canopy cover, and differed from other sites in having a canopy comprising trees and tall shrubs.

3. The amount of bare ground was greater, and the percentage leaf litter cover less, at rehabilitated sites than at undisturbed locations. After adding mulch at Site 2 in November 1987, leaf litter cover and depth were comparable to those at undisturbed sites. Sedges were poorly represented at Site 3. Although sedges were more numerous at Site 2, they were not as abundant as at the undisturbed sites.

4. Fourteen reptile, seven frog and four mammal species were caught or observed during the study. Species diversity varied between the three undisturbed sites, probably because of differences in vegetation structure and plant associations at those sites. Reptiles and mammals were poorly represented at the rehabilitated sites, although some species occurred in numbers comparable to those at undisturbed sites. These included *Diplodactylus spinigerus* (Western Spiny-tailed Gecko) and *Mus musculus* (House Mouse). Other species that appeared to use the rehabilitated sites for at least part of the year were: the small skinks, *Ctenotus schomburgkii* and *Ctenotus pantherinus* (both at Site 3), *Pogona minor* (Western Bearded Dragon), *Ctenophorus maculatus* (Spotted Dragon), *Tiliqua rugosa* (Bobtail), *Pseudomys albocinereus* (Ash-grey Mouse) and

Tarsipes rostratus (Honey Possum) (all trapped in low numbers with the exception of *T. rostratus).*

5. Twenty three species of bird were identified during the study. Many of these were well represented at both undisturbed and rehabilitated sites. Honeyeaters occurred in the greatest numbers, especially at Site 3, with *Phylidonyris nigra* (White-cheeked Honeyeater) being most abundant, followed by *Phylidonyris melanops* (Tawny-crowned Honeyeater) and *Lichmera indistincta* (Brown Honeyeater). Birds recorded at Site 3, but not observed at other sites, included *Anthochaera carunculata* (Red Wattlebird), *Lichenostomus virescens* (Singing Honeyeater), *Rhipidura fuliginosa* (Grey Fantail), and *Chrysococcyx basalis* (Horsfield's Bronze-Cuckoo). Site 2 did not support bird species such as *Malurus splendens* (Splendid Fairy-wren), *Malurus lamberti* (Variegated Fairy-wren) and *Sericornis fuliginosus* (Calomanthus) that were common at the adjacent Site 1, nor did it support populations of honeyeaters throughout the year in the same way as all other sites.

6. Poor representation of most reptile, mammal and some bird species at rehabilitated sites was probably due to the soil characteristics at those sites, modest leaf litter cover, relatively large areas of bare ground, and low shrub cover. Many heathland vertebrate species are adapted to, or show a preference for, sandy soils, largely because of their burrowing activity. Soil at the rehabilitated sites was generally cracked and hard in the summer months, and often waterlogged in winter. Relatively poor litter cover at rehabilitated sites would have limited the availability of shelter for reptiles and mammals. Species that occurred in reasonable numbers at the rehabilitated sites were either semi-arboreal (*D. spinigerus*, *P. minor* and *T. rostratus*) or opportunistic in their breeding and feeding ecology (*Mus musculus* and to a lesser extent *T. rostratus*). The absence of a dense low shrub layer at Site 2 (due to its relatively young age) and Site 3 (because of the rehabilitation techniques implemented) may have been responsible for the absence of some mammals and birds such as fairy-wrens.

7. Nesting honeyeaters and resident populations of *T. rostratus* require nectar throughout the year if they are to survive. Undisturbed heathlands at Eneabba are able to meet these requirements due to their high plant species diversities and asynchronous flowering phenologies. Sites 4 and 5 had plants that were particularly important sources of nectar during the winter months, while Site 1 (together with rehabilitated Sites 2 and 3) provided most nectar during the summer. Although honeyeaters and *T. rostratus* foraged to some extent on flowers of the same plant species, they often preferred different species. The presence of large numbers of honeyeaters at rehabilitated Site 3 is thought to have been

due to the diversity of nectar-producing species and high density of flowers per plant, combined with the mobile opportunistic behaviour of honeyeaters.

8. While pollination and seed set almost certainly occurs at the rehabilitated sites, thus satisfying some requirements for a self-regenerating system, the deficiency of burrowing vertebrates suggests that invertebrates capable of making soil more friable and micro-fauna needed for nutrient recycling may also be lacking.

Contents

1. General Introduction

Over the past few decades, considerable attention has been paid to the impact that mining has on native flora and fauna, and on problems encountered during the rehabilitation of disturbed habitats (Fox & Fox 1978; Majer *et al.* 1982; Wykes 1984; Collins *et al.* 1985; Walker *et al.* 1986). This development has been partly the result of a general increase in community concern and awareness of environmental matters, but also a consequence of Federal and State Government regulations that require strict environmental impact appraisal of mining activities.

Research relating to the rehabilitation of mined lands initially tended to concentrate on vegetation. The realisation that animals can be used as reliable bio-indicators of the progress of land reclamation, however, has resulted in the gathering of a significant body of faunal data (U.S. Congress Office of Technology Assessment 1986; Majer 1989a). Most of the initial work involving animals was undertaken in the U.S.A., although significant findings have emerged from Australian studies in recent years. For instance, Majer *et al.* (1982) has demonstrated that ant recolonisation is a useful indicator of the extent and speed of land rehabilitation following mining in one-to-three year old sand mining rehabilitation plots near Eneabba, Western Australia. In another study of rehabilitated sand mines on North Stradbroke Island, in Queensland, Majer (1985) found that recolonisation proceeded at a faster rate than at Eneabba, at least partially because of climatic differences between the two regions. Such findings suggest that it may be necessary to recognise a "gradient" of recolonisation rates across Australia, and that these should be taken into account when assessing the success of rehabilitation in various regions.

Considerable attention has also been paid to the sequence and speed with which vertebrate species return to rehabilitated areas, both in the iron ore and alumina mining areas of Western Australia, and sand mining regions near the east coast of Australia (Collins *et al.* 1985). For example, Fox & Fox (1984) demonstrated that small mammal succession after sand mining is similar to that for pyric succession in natural habitats, but extends over a longer time scale. Differences in recovery times have been attributed to the fact that mining causes greater disruption of the substrate than does fire. Non-linear relationships between regeneration age and many of the environmental variables monitored in this study made it difficult to estimate recovery times after mining and fire, although Fox & Fox (1978) had previously predicted that a minimum of 20 years would be necessary for vegetation and *Pseudomys novaehollandiae* biomass in rehabilitated plots to reach values encountered on undisturbed heath control plots.

The introduced house mouse, *Mus musculus*, is recognised as an opportunistic first coloniser during both pyrrhic and post-mining succession in eastern Australia, with 73 % of the variation in its biomass accounted for by three environmental variables: percentage bare sand, hardness of soil in the first 30 cm, and the presence of uniform scrubby vegetation in the structural layer between 50 cm and 2 m (Fox & Fox 1984). This species is ultimately replaced by *P. novaehollandiae*, whose numbers peak 8-9 years after topsoil replacement. Approximately 96 % of *P. novaehollandiae* biomass variation is accounted for by plant species diversity, an index representing the proportion of heath species present and a measure of soil hardness (Fox & Fox 1978).

Interspecific competition between *M. musculus* and *P. novaehollandiae* on sand mine rehabilitation plots has been experimentally confirmed by Fox & Pople (1984) and Fox & Gullick (1989), who concluded that such competition is one of the mechanisms controlling the replacement of species in a succession following disturbance. To explain the process of succession itself, a "habitat accommodation model" was proposed by Fox (1982), with species entering a succession and reaching peak abundance as the externally-controlled changes in vegetation fulfilled their habitat requirements. Species leave the succession, or diminish in abundance, as values for environment parameters deviate from those that are optimal for these species.

In Western Australia, studies of an iron ore waste dump at Newman have shown that an "encouraging number" of small mammal and reptile species returned within two years of initial revegetation, despite limited site accessibility up a 65 m slope devoid of plant material (Walker *et al.* 1986). These results tend to support Majer's (1989b) hypothesis that restoration success occurs more rapidly and easily in areas with relatively harsh natural environments. Similarly, in a study of three south-east Queensland rainforests, Barry (1984) found that those areas with infertile podsol soils and a history of logging disturbance tended to support a greater proportion of opportunistic small mammal species than did undisturbed areas with fertile krasnozem soils.

Ideally, baseline studies of animal distribution and abundance should be conducted before mining takes place, since it is hoped that eventual rehabilitation of mined areas will produce ecosystems that resemble the originals. Where studies of this type are not possible, faunal surveys are usually undertaken once rehabilitation has commenced and comparisons made with data gathered during similar surveys at nearby undisturbed, natural sites. Most of the studies referred to above have involved comparisons of this type, as have recent surveys of reptiles, mammals and birds at mineral sand mines near Eneabba (Dunlop 1981), and reptiles (Nichols & Bamford 1985) and birds (Nichols *et al.*

1982; Wykes 1984; Collins *et al.* 1985) at bauxite minesites in the Jarrah forest of Western Australia.

Generally, comparisons of fauna in undisturbed and rehabilitated areas culminate in recommendations as to ways in which various aspects of the rehabilitation process could be improved. For instance, it may be desirable to modify the revegetation program so as eventually to provide a greater variety of vegetation layers and increase total ground cover, if bird species diversity is to be increased (Willson 1974). Modifications to practices that improve the physical structure of the soil, and the energy content, composition and distribution of litter may also be necessary if the return of invertebrates is to be facilitated (Bell & Sipp 1975).

The Eneabba area of Western Australia, in which studies reported later in this report were undertaken, has been described by Hopkins & Hnatiuk (1981) and Elkington (1986) as one of extreme floristic diversity. Nevertheless, large-scale open cut sand mining activities have been taking place in the region since 1973, and there are prospects of expansion in the future. Associated Minerals Consolidated (AMC), (now known as Renison Gold Consolidated (RGC)), one of the major companies involved in mining operations at Eneabba, has consistently endeavoured to re-establish functioning ecosystems at sites that have been mined. To promote this objective, a number of research projects in collaboration with tertiary institutions have been encouraged and supported by the company. For instance, several research projects dealing with seed germination of *Banksia* species or invertebrate colonisation of rehabilitated mined sites have been undertaken by students of Curtin University of Technology (Bowyer 1985; Elliott 1986; Harris 1987; Hoyle 1988).

The major purpose of the study outlined in this report was to assess the extent to which native vertebrates have become re-established in rehabilitated areas controlled by RGC at Eneabba. More specifically, the study was designed to:

1. Obtain and compare seasonal vertebrate species richness and abundance data at three undisturbed and two rehabilitated heathland sites over a period of 14 months,

2. Compare physical and vegetation characteristics presumed to influence the suitability of the above mentioned sites as habitats for vertebrates, and

3. Determine the feeding (and where possible, breeding) requirements of vertebrates known to occur on undisturbed sites in the area.

2. Site Description

2.1 Location

Sclerophyllous heathland vegetation, of the type found on the northern sandplain near Eneabba, Western Australia, is commonly referred to as "kwongan" (George *et al.* 1979; Hopkins & Hnatiuk 1981). The section of "kwongan" associated with investigations outlined in this report is situated about 10 km south of the Eneabba township, approximately 280 km north of Perth and 30 km inland. It lies within an area defined by latitudes 29° 50' - 29° 55' south and longitudes 115° 15' - 115° 18' east, near the western edge of Beard's (1976) Tathra Vegetation System, in the Irwin Botanical District of the South-western Botanical Province of Australia.

Competing land uses proposed for the Eneabba region include agriculture, the establishment of nature reserves and mining for coal and heavy minerals. Open-cut sand mining for materials such as ilmenite, rutile, zircon and monazite has taken place since 1973. At one stage, mineral tenements on the area were held by three companies: Western Titanium Ltd. (now Renison Gold Consolidated Ltd.), Allied Eneabba Pty. Ltd. (now incorporated in Renison Gold Consolidated Ltd.) and Ilmenite Pty. Ltd. (now Westralian Sands Ltd.). Only Renison Gold Consolidated Ltd. (RGC) currently conducts mining operations in the region. The sites being worked by this company are portions of two flora and fauna conservation reserves, both of which were vested in the W.A. Wildlife Authority in 1972. It is hoped that the mined sites will eventually be reincorporated into these reserves.

Material presented below provides background information relating to the climate, flora, fauna, geology and physiography of the Eneabba area. Details of the mining and rehabilitation practices followed by RGC are also given, together with information relating to the undisturbed and rehabilitated sites used in the present study.

2.2 Geology and physiography

In general, the topography of the Eneabba region is that of a long westerly slope, from the lateritised Mesozoic Dandaragan plateau and Gingin scarp in the east (300 m a.s.l. and 100 m a.s.l., respectively), across the sandy dunes and swales of the Eneabba plain. This plain slopes down gently to approximately 50 m a.s.l. at its western edge, where it abuts an undulating coastal limestone platform covered by a veneer of sand dunes. Alluvial and colluvial deposits of gravel, sand and clay which cover the Eneabba plain have been deposited there by streams flowing seaward from the easterly plateau (Hopkins & Hnatiuk 1981).

During the Tertiary to Pleistocene, beach deposits containing rich concentrations of heavy minerals were deposited just east of today's Gingin scarp, which represents an ancient coastline (Baxter 1972), and are now situated not far beneath the dune and swale sequence of the Eneabba plain. Laterisation of the scarp and plateau regions occurred in the early Tertiary, resulting in deep weathering of surface layers that gradually developed into horizons of leached sand overlying massive laterite (Beard 1976).

2.3 Soils

A soils map produced by the Department of Lands and Surveys for agricultural purposes, shows the study area to consist of a highly varied mixture of grey and yellow sand units, interspersed with lateritic gravels. Northcote *et al.* (1967) mapped the soils of the Eneabba plain as leached and sandy, containing considerable ironstone gravel in the A horizons on rising ground leading up to the eastward scarp. George *et al.* (1979) have suggested that soils of the region are probably the most varied in the South - West of Western Australia.

Examination of soil profiles on leases held by Allied Eneabba Pty Ltd in the early 1980's showed soils to be generally low in several mineral nutrients and moisture, particularly during the usual summer drought. Although relatively high phosphorus levels were found, these are believed to reflect the presence of monazite, a phosphorus-bearing mineral whose phosphorus is unavailable to plants (Hopkins & Hnatiuk 1981).

2.4 Climate

The climate of the South-West Botanical Province has generally been described as "Mediterranean" (George *et al.* 1979). In the Eneabba region, there is an average annual rainfall of 550 mm, most of which falls in the winter months of June, July and August. During the summer, temperatures often exceed 40 ^{o}C and there is generally a shortage of moisture that can be used by fauna and flora (Beard 1976).

The total rainfall recorded at Eneabba during 1987 and 1988 was 491 mm and 682 mm, respectively, and differed from the mean annual rainfall of 517 mm for the previous 30 years (data supplied by the Bureau of Meteorology). Monthly rainfall in April and May was higher in 1988 than 1987, and no summer precipitation occurred in 1988 although rains were recorded in February and December of 1987 (Figure 1).

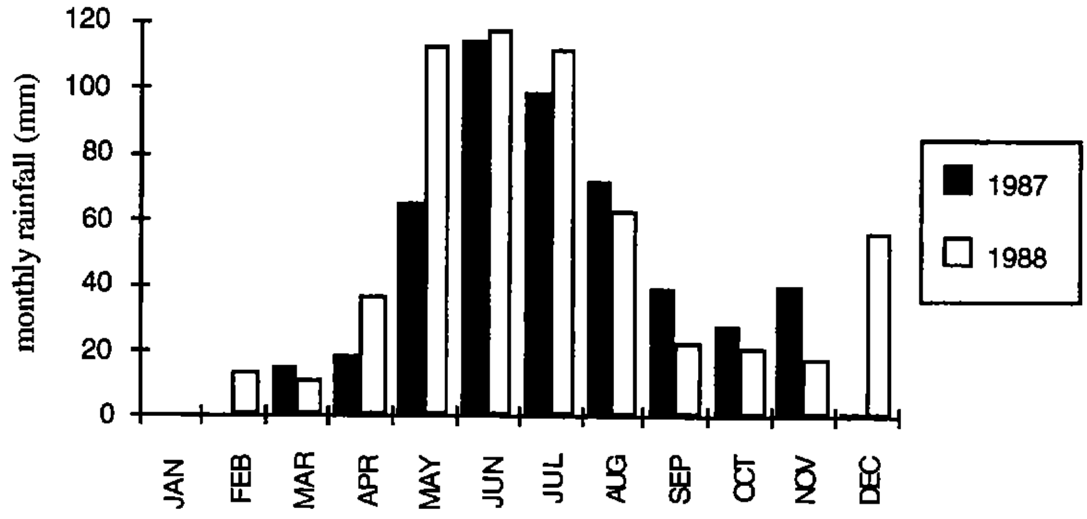

Figure 1: Monthly rainfall at Eneabba in 1987 and 1988.

2.5 Vegetation and flora

A vegetation survey conducted by Hopkins & Hnatiuk (1981) approximately 10 km south of the township of Eneabba, identified 429 species of vascular plants belonging to 50 families and 162 genera. These findings are in agreement with those reported by George *et al.* (1979). Characteristic of this region is the proliferation of two particular plant families: the Proteaceae, predominantly found on lateritic soils, and the Myrtaceae, which generally occurs on sandier substrates.

The "kwongan" vegetation found near Eneabba consists of scrub - heath assemblages and patches of *Melaleuca* thicket, with occasional scattered trees and woodlands (Hopkins & Hnatiuk 1981). Scrub-heath is composed of scattered shrubs ranging from 1-2 m in height, with a denser layer of lower shrubs (Beard 1976). Scattered but common small trees include *Banksia menziesii*, *B. hookeriana*, *B. prionotes*, *Eucalyptus todtiana*, *E. macrocarpa*, *Xylomelum angustifolium*, a few *Nuytsia floribunda*, and occasional mallee clumps of *E. tetragona*. Tall shrubs generally include *Adenanthos cygnorum*, *B. attenuata*, *Casuarina humilis* and several species of *Acacia*, *Calothamnus*, *Eremaea*, *Hakea* and *Jacksonia*. In areas of low heath, scattered *Xanthorrhoea* are common. Lower shrubs generally include *B. candolleana*, *B. lanata*, *B. leptophylla*, *B. grossa*, *Beaufortia elegans*, and species of *Calytrix*, *Dryandra*, *Conospermum*, *Petrophile* and *Verticordia*. In the herbaceous layer, *Anigozanthos humilis*, some Restionaceae and species of *Conostylis* and *Hibbertia* are often represented.

The extreme heterogeneity of scrub-heath flora makes it difficult to assess the dominance of particular species and to precisely determine variations within plant communities. Nevertheless, three major types of assemblage have been identified in the Eneabba area by Hopkins & Hnatiuk (1981). These correspond to major soil units, *viz*., (1) lateritic gravels and sands, (2) sand ridges and dunes, and (3) winter wet depressions, with plant species richness declining from group 1 to group 3.

Winter wet depressions, found in low-lying swales between dunes and sand ridges, are very heterogeneous. Although less widespread and with a lower species diversity than the other two groups, they have been recommended by Hopkins & Hnatiuk (1981) as the unit most in need of special conservation attention. A number of wetland plant species appear to have very restricted distributions and many wetlands have already been severely affected or destroyed by mining activities.

2.6 Fauna

All mammalian species, and most of the amphibians, reptiles and birds, captured or observed by Dunlop (1981) and McGarvie (1983) at Eneabba were also detected during this study. The most frequently seen mammals were the Honey Possum *Tarsipes rostratus*, the Ash-grey Mouse *Pseudomys albocinereus*, the White-tailed Dunnart *Sminthopsis granulipes* and the House Mouse *Mus musculus*. Reptiles included dragons such as *Pogona minor*, *Ctenophorus maculatus* and *Tympanocryptis adelaidensis*; skinks such as *Tiliqua rugosa*, *Ctenotus fallens*, *C. schomburgkii*, *C. pantherinus* and *Lerista praepedita*; the legless lizard *Lialis burtonis*; the gecko *Diplodactylus spinigerus*; and snakes such as *Notechis curtus*, *Rhinoplocephalus gouldii* and *Vermicella littoralis*. Amphibians such as the frogs *Neobatrachus pelobatoides*, *Heleioporus albopunctatus*, *H. eyrei*, *Pseudophryne guentheri*, *Limnodynastes dorsalis* and *Myobatrachus gouldii* were also captured. Birds such as White-cheeked, Tawny-crowned, Brown and Singing Honeyeaters (*Phylidonyris nigra*, *P. melanops*, *Lichmera indistincta* and *Lichenostomus virescens*) were netted, while other major species observed were White-backed and Welcome Swallows (*Cheramoeca leucosternum* and *Hirundo neoxena*), Black-faced Woodswallows *Artamus cinereus*, Willie Wagtails *Rhipidura leucophrys*, Splendid, White-winged and Variegated Fairy-wrens (*Malurus splendens*, *M. leucopterus* and *M. assimilis*), Richard's Pipits *Anthus novaeseelandiae*, Crested Pigeons *Ocyphaps lophotes*, Galahs *Cacatua roseicapilla*, Carnaby's White-tailed Black Cockatoos *Calyptorhynchus latirostris*, Port Lincoln Ringnecked Parrots *Platycercus zonarius*, Australian Kestrels *Falco cenchroides*, Black-shouldered Kites *Elanus notatus* and Australian Ravens *Corvus coronoides*.

2.7 Study plots

Of the five sites chosen for this study, two (Sites 2 and 3) had been rehabilitated after sand mining. The remaining sites were relatively undisturbed "controls", situated adjacent to the AMC (hereafter referred to as RGC) minesite (Figure 2). "Control" sites were chosen so as to represent the three major sandplain heath assemblages referred to above.

Of the rehabilitated sites, Site 2 was mined and rehabilitated by RGC, while Site 3 had residual tailings, 4-5 m deep, placed on top of its natural vegetation by Allied Eneabba. Vegetation at Site 3 was then re-established by planting and seeding. During the mining process at Site 2, the topsoil was stripped and stockpiled separately from the mulch. Deep pits were then cut and mined. Most rehabilitation work at Site 2 took place between January and May of the first year after the cessation of mining. Residual tailings were returned and contoured to fill the pits, after which topsoil was returned and tyned. Mulch was spread over the topsoil, and the area seeded with a cover crop of oats or cereal rye to encourage stabilisation of the soil. To ensure cover-crop survival, fertiliser consisting of 100 kg of superphosphate and 50 kg of nitrogen per hectare was applied (Jefferies, pers. comm.). A native seed mix was then collected from adjacent unmined areas and sown either by hand or machine. In June of the following year, plantings of nursery-grown seedlings took place. Weeding of rehabilitated areas also occurred, with particular attention paid to the eradication of introduced weeds such as Capeweed and Speargrass.

Undisturbed Site 1 (Figure 3; low, open heath) had vegetation of the type described by Hopkins & Hnatiuk (1981) as "Group 1" (i.e. heath assemblages on lateritic sands and gravels). Rehabilitated Site 2 (Figure 4; rehabilitation commenced in 1982) had vegetation prior to mining that also belonged to "Group 1". Although referred to as undisturbed i.e., it was unmined, Site 1 had vegetation that had been cut for mulch to a height of 30-50 cm, approximately three years prior to commencement of the present study. Nevertheless, essentially all of the species considered typical of "Group 1" habitats (*Adenanthos drummondii, Beaufortia bracteosa, Conostylis androstemma, Darwinia sanguinea, Dryandra bipinnatifida, D. carlinoides, D. kippistiana, D. vestita, Grevillea synapheae, Haemodorum paniculatum, Hibbertia polystachya, Isopogon adenanthoides, I. linearis, Lepidobolus* sp. AJMH, *Macropidia fuliginosa* and *Petrophile striata*) were represented. At the time of the present study, vegetation on Site 2 differed significantly from that found at Site 1.

Sites 1 and 2 were situated adjacent to each other on the eastern edge of the RGC minesite, and were separated only by a wire mesh fence and a narrow, open piece of ground that was a disused vehicle track. The fence acted mainly as a windbreak, but also

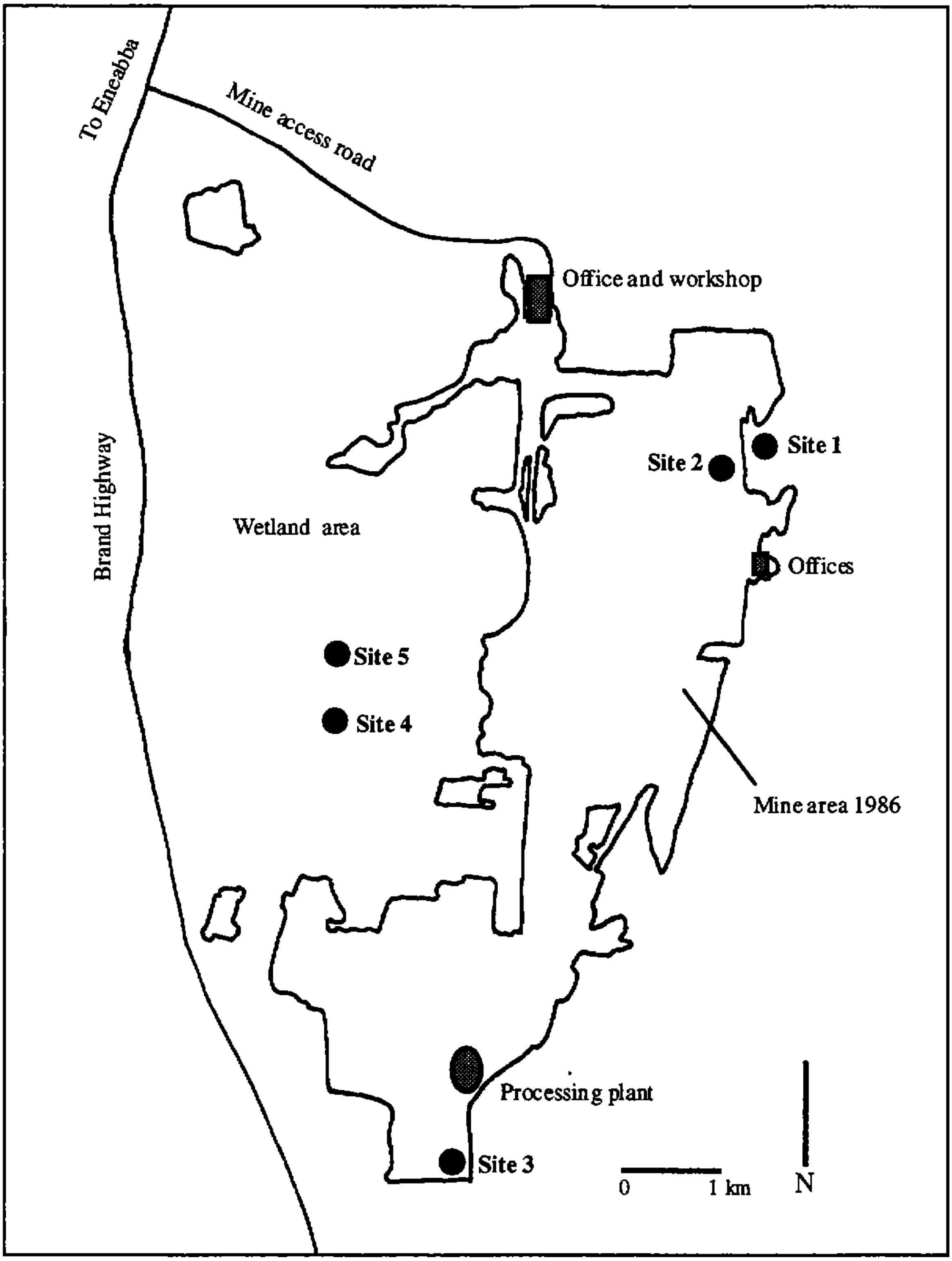

Figure 2: Locations of undisturbed (1, 4 and 5) and rehabilitated (2 and 3) study sites on the northern sandplain near Eneabba.

protected vegetation on Site 2 from foraging by animals such as kangaroos and emus. Gaps under the fence ensured easy access to the rehabilitated area for reptiles, amphibians and small mammals. Both sites were cut off from natural heathland areas to the east by a major haul-road, which was frequently used by heavy machinery.

Figure 3: Site 1, with natural vegetation that had been slashed during 1984.

Figure 4: Site 2, at which rehabilitation commenced in 1982.

Site 3 (Figure 5; rehabilitation commenced in 1977) originally had "Group 1" vegetation, although the rehabilitation techniques employed after mining were rather less sophisticated than those developed in later years and used at Site 2 (Jefferies, pers. comm.). This site lay in the southeast corner of the RGC lease and was bounded to the south and east by an unsealed road. There was no perimeter fencing, although a wire mesh windbreak (erected in November 1987) ran through the centre of the site, and an elevation of approximately 5 metres above the adjacent natural heathland may have served as a partial deterrent to the movement of large fauna on to the site.

Sites 4 (Figure 6; *Banksia-Xylomelum* heathland on a sandy ridge) and 5 (Figure 7; a low-lying winter wet depression, located in a swale beneath the dune ridge of Site 4), were separated by a distance of 380 metres. Both sites were approximately 2 km from current mining operations, and experienced few disturbances of any kind. Vegetation at Site 4 conformed to Hopkins and Hnatiuk's "Group 2" classification, and included species such as *Adenanthos cygnorum, Banksia hookeriana, Pityrodia hemigenioides, Thysanotus rectantherus*, as well as *Eucalyptus todtiana, Synaphea polymorpha* and *Xylomelum angustifolium*. "Group 3" vegetation at Site 5 was very heterogeneous, consisting principally of sedges, shrubs and a few small trees.

Figure 5: Site 3, at which rehabilitation commenced in 1977.

Figure 6: Site 4, heathland characterised by *Banksia / Xylomelum* vegetation.

Figure 7: Site 5, heathland with vegetation located on a low-lying wet depression.

3. Vegetation Analysis

3.1 Introduction

Rehabilitation of land that has been mined is usually undertaken in such a way as to render it capable of supporting activities that were undertaken prior to mining. In cases where areas of natural vegetation have been mined, e.g., sites on flora and fauna reserves at Eneabba, the prime objective is to produce a self-sustaining ecosystem, using endemic plant species that can effectively support the local fauna (Brooks & Jefferies 1990). To achieve this goal, techniques have been developed to re-establish vegetation with a similar diversity, density and structure to that which prevailed prior to mining.

In this study, vegetation at three undisturbed and two rehabilitated sites was assessed and compared in terms of its capacity to provide suitable habitats for vertebrates that occurred in the Eneabba area. Parameters used as a basis for comparisons were:

(a) Ground litter cover, described as percentage cover and depth,
(b) Plant density, measured as the number of live plants per unit area,
(c) Canopy cover, measured as the area of canopy cover per unit area,
(d) Presence and density of the major nectar- and pollen- producing plants,
(e) Flowering phenologies of potentially important food plants.

3.2 Methods

3.2.1 Ground litter cover

Ground litter cover was assessed at each of the five study sites during the first half of 1987, by estimating the percentage litter cover in twenty 25 cm x 25 cm quadrats. Each quadrat was located approximately one metre to the right of a pitfall trap (see Section 4 for details), and where litter appeared to have remained undisturbed. Estimated values for the quadrats were used as a basis for calculating the mean percentage litter cover for each site.

Five litter depth measurements were made per quadrat: one near each of the corners and one approximately in its centre. Litter depths for each of the 20 quadrats were averaged and used to give a mean litter depth for the site. Litter cover and depth were measured only once at four of the sites, as it was assumed that values would not change significantly within the course of a year (Majer, pers. comm.). The addition of mulch to

Site 2 by RGC staff in November 1987, however, made it necessary for these measurements to be repeated at this site in January, 1988.

A "litter index" (litter cover value x litter depth value) was calculated for each quadrat, and a mean index estimated per site. A coefficient of variation was also calculated for each site, and used to indicate the patchiness of litter distribution. Between-site comparisons of total litter availability (litter index) and patchiness (coefficient of variation) were then made (Majer, pers. comm.).

3.2.2 Vegetation density and canopy cover

Vegetation density and canopy cover were measured at Sites 1, 4 and 5, and vegetation density at Site 2, in November 1987. Canopy cover for Site 2 was determined by J. Elkington, Consulting Botanist to RGC, in November 1988, as were vegetation density and canopy cover for Site 3.

Twenty 1 m^2 quadrats were laid out along five 20-metre transects at each site, with transects positioned around the periphery of the pitfall grid area. All live plants growing within the quadrats were identified and counted. Vegetation densities were then estimated and expressed as plants/100 m^2. Canopy cover was estimated by identifying all plants that intercepted the transects at a given site and measuring the amount of a 0.01 m wide strip along the transects that was covered. Mean values were expressed as cm^2/100 cm^2 for each species.

3.2.3 Flowering phenology

Flowering phenologies for the main nectar- and pollen-producing plant species were determined at each site by counting the number of non-senescent flowers or inflorescences present on numbered plants in July, September and November of 1987, and January, March and May of 1988. Where possible, counts were made for at least 30 plants per species. Comparisons were then made between flowering patterns at the three undisturbed and two rehabilitated sites.

3.3 Results

3.3.1 Ground litter cover

Mean litter depth, percentage cover and index were substantially less for both rehabilitated sites than the three undisturbed sites when measured during the first half of

1987, although mulching later that year resulted in significant increases in litter cover at Site 2 (Figure 8). Litter cover was substantially greater at undisturbed Sites 4 and 5 than at Site 1.

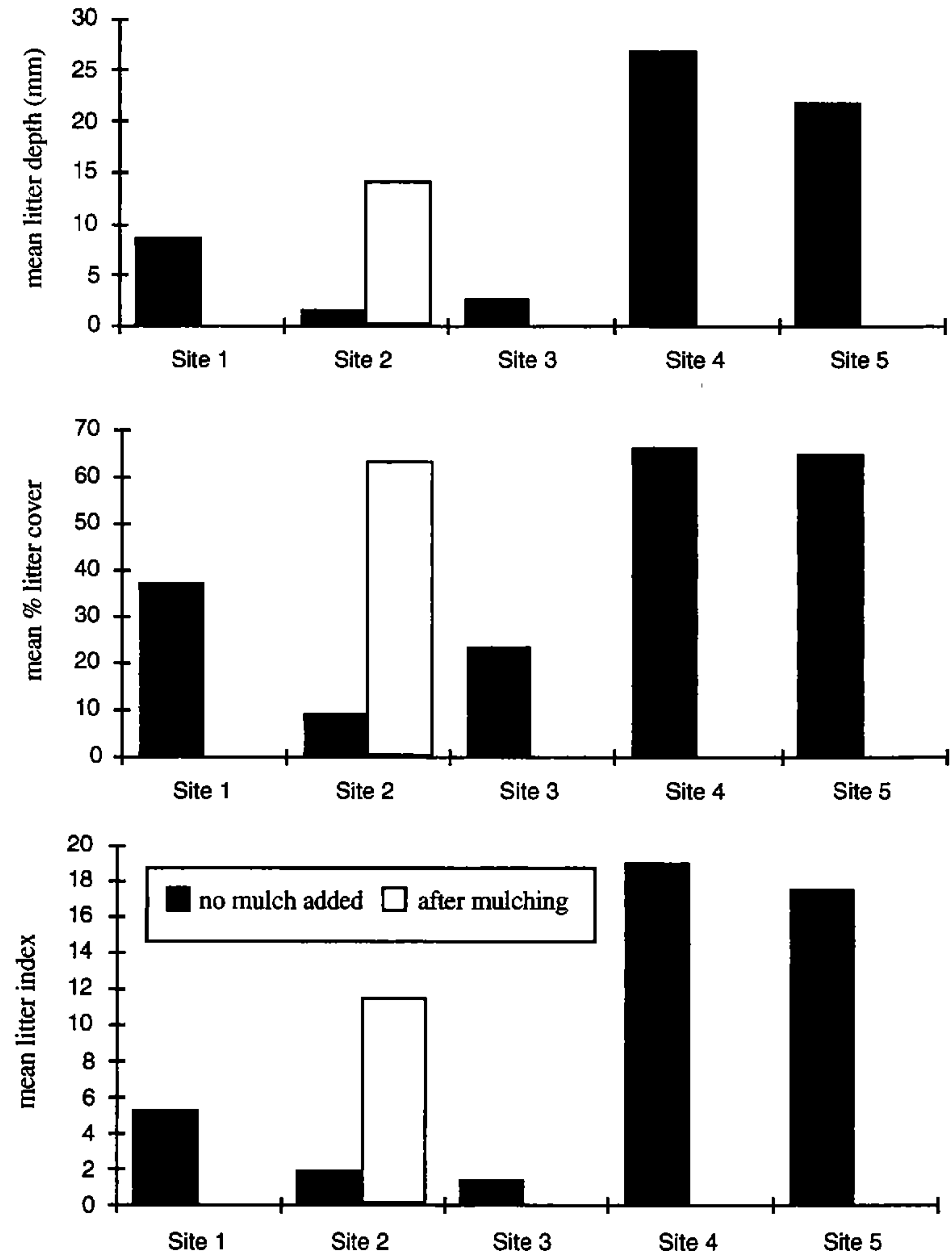

Figure 8: Mean litter depths, percentage litter covers and litter indices for undisturbed and rehabilitated sites.

Coefficients of variation for the litter index indicate that litter was more patchily distributed at Sites 1, 2 and 3 initially than at Sites 4 and 5 (Figure 9). Mulching at Site 2, however, decreased the patchiness of litter ground cover at that site, although not to levels comparable with those at Sites 4 and 5.

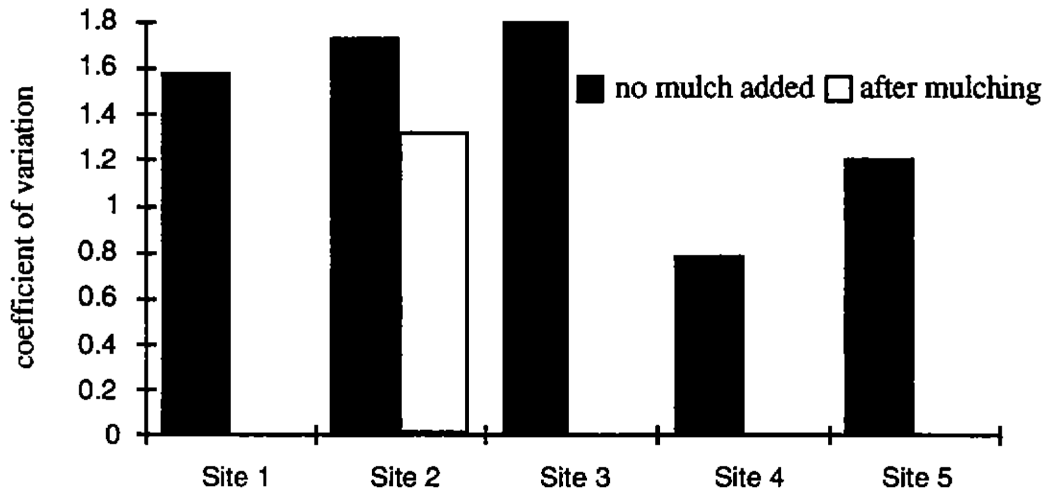

Figure 9: Patchiness of litter distribution at undisturbed and rehabilitated sites, as indicated by coefficients of variation for litter indices.

3.3.2 Vegetation density and canopy cover

Site 3, where rehabilitation commenced in 1977, had fewer plant species, and a lower overall plant density and canopy cover than any of the other sites (Table 1; Appendices 1 and 2). Site 2, however, had plant density and species abundance values that were only marginally less than those for the adjacent undisturbed Site 1. The presence of a large number of relatively young seedlings at Site 2 would help to account for these observations, and for the fact that canopy cover values were low at that site. Marked differences in plant densities and canopy covers at Sites 4 and 5 can be explained by the fact that many plants at Site 5 tended to be broad and overlapping.

Table 1: Plant density and canopy cover at undisturbed and rehabilitated sites. # indicates measurements made at Sites 1, 4 and 5 in November 1987, and at Sites 2 and 3 in November 1988. * denotes numbers of plant species recorded in plant density analysis.

Site number	Plant density (plants / 100 m^2)	Number of species*	Canopy cover (cm^2 / 100 m^2)
1	146.72	112	95.3
2	126.60	94	?
3	86.75	52	44.0
4	317.37	84	86.5
5	91.47	68	144.4

Table 2: Plants with greatest densities and canopy covers. * major nectar/pollen producers; ^ species that are sedges.

Site no.	Plant species	Plants/100 m2	Plant species	cm2/100 m2
1	*Drosera paleacea*	4.75	*Allocasuarina humilis*	10.05
	Schoenus subbarbatus^	4.15	*Ecdeiocolea monostachya*^	5.82
	Goodenia caerulea	3.74	*Banksia grossa**	4.63
	Logania spermacocea	3.17	*Restio sphacelatus*^	4.52
	Tetraria octandra^	2.57	*Jacksonia floribunda*	3.16
	Restio sphacelatus^	2.45	*Dryandra shuttleworthiana**	3.01
	Calytrix superba	2.40	*Daviesia divaricata*	2.90
	Glischrocaryon aureum	2.33	*Allocasuarina microstachya*	2.65
	Amphipogon turbinatus^	2.24	*Xanthorrhoea reflexa*	2.54
	Mesomelaena stygia^	2.12	*Hakea candolleana**	2.38
2	*Melaleuca hamulosa*	4.31	Data not available for this site	
	Beaufortia bracteosa	4.00		
	Melaleuca acerosa	2.45		
	Isopogon tridens	2.40		
	Eremaea violacea	2.36		
	Melaleuca trichophylla	2.09		
	Thysanotus teretifolius	2.00		
	*Dryandra shuttleworthiana**	1.85		
	Conostylis aculeata	1.80		
	Beaufortia elegans	1.76		
3	*Beaufortia elegans*	12.00	*Banksia leptophylla**	8.00
	Lechenaultia stenosepala	8.00	*Isopogon adenanthoides*	6.55
	Drosera paleacea	5.22	*Hakea costata**	4.90
	Melaleuca acerosa	4.87	*Beaufortia elegans*	2.75
	Eremaea violacea	2.07	*Schoenus brevisetis*^	2.70
	*Calothamnus sanguineus**	2.00	*Mesomelaena tetragona*^	2.60
	*Dryandra nivea**	2.00	*Lambertia multiflora**	2.50
	Acacia pulchella	1.86	*Petrophile drummondii*	2.32
	Conostylis dielsii	1.67	*Melaleuca acerosa*	2.30
	Conostylis neocymosa	1.50	*Hibbertia aff furfuracea*	2.25
4	*Banksia hookeriana**	42.18	*Xylomelum angustifolium*	8.47
	*Banksia grossa**	31.95	*Banksia candolleana**	7.60
	Beaufortia elegans	13.89	*Banksia grossa**	7.00
	Hakea corymbosa	10.91	*Scholtzia laxiflora*	6.99
	Stirlingia latifolia	9.65	*Actinostrobus acuminatus*	5.74
	*Banksia candolleana**	9.45	*Eucalyptus todtiana**	4.25
	Pityrodia hemigenioides	7.48	*Banksia hookeriana**	3.25
	Restio sphacelatus^	6.30	*Banksia leptophylla**	3.15
	Daviesia divaricata	6.19	*Banksia attenuata**	2.60
	Unidentified species^	5.09	*Conostephium pressii*	2.45
5	*Beaufortia elegans*	6.13	*Verticordia densiflora**	22.90
	Caladenia flava	4.46	*Calothamnus cf villosus**	22.30
	Mesomelaena stygia^	3.50	*Caladenia flava*	15.60
	Schoenus subbarbatus^	2.38	*Banksia lanata**	12.08
	Drosera paleacea	2.00	*Xylomelum angustifolium*	8.75
	Schoenus brevisetis^	2.00	*Cassytha flava*	7.63
	*Calothamnus cf villosus**	1.88	*Scholtzia laxiflora*	6.65
	*Verticordia densiflora**	1.86	*Phymatocarpus porphyrocephalus*	5.50
	Lepidobolus chaetocephalus^	1.83	*Hakea obliqua*	4.55
	Melaleuca acerosa	1.68	*Eremaea beaufortioides*	4.15

Minimal overlap occurred between the most abundant plant species at the five sites (Table 2). Of the 10 most abundant plant species at Sites 1, 4 and 5, respectively, six, two and four were sedges. No sedges were among the top 12 species at Sites 2 and 3, although the total number of sedge species detected at Site 2 (all with densities < 1.6 plants/100 m^2) were comparable to those at undisturbed sites (Table 3). Few of the plant species visited by mammals or birds (see Sections 4 and 5 of report) were among the most abundant species at Sites 1 and 2, but several were especially common at Site 4. Nevertheless, at least 16 significant nectar- and/or pollen-producing species were found at each of the sites (Table 4).

Table 3: Plant densities and canopy covers for sedges (Restionaceae and Cyperaceae).

Plant species	Plant density (plants/100 m2)					Canopy cover (cm2/100 m2)				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
Alexgeorgea arenicola	1.50			2.65	1.25	0.20			0.35	
Amphipogon turbinatus	2.24	1.00		2.04	1.33	1.50			0.43	
Caustis dioica	1.18	1.48				1.85				
Caustis indet.		1.50								
Ecdeiocolea monostachya	2.04	1.20		3.57		5.82			0.99	
Lepidobolus chaetocephalus	1.64			4.11	1.83	1.85			1.69	1.63
Lepidosperma tenue	1.48	1.45	1.00	2.40	1.00				0.23	
Loxocarya cinerea					1.00					
Loxocarya fasciculata		1.14								
Lyginia barbata	1.29	1.23	1.00	4.09	1.00				0.30	
Mesomelaena stygia var. 1	2.12	1.14	1.13	2.98	1.67	1.85		0.53	0.38	0.74
Mesomelaena stygia var. 2	1.00	1.39		2.73	3.50					0.60
Mesomelaena tetragona	1.00	1.20	1.00			0.80		2.60		
Neurachne alopecuroidea	1.00				1.00					
Restio sphacelatus	2.45	1.00		6.30	1.33	4.52			0.84	1.22
Schoenus brevisetis	1.77	1.14	1.00	1.35	2.00	0.56		2.70	0.12	
Schoenus curvifolius	4.15			3.14					0.13	0.35
Schoenus pedicellatus				1.82					0.30	0.20
Schoenus subbarbatus		1.43		4.17	2.38	1.76			0.64	
Schoenus unispiculatus			1.00							
Schoenus aff pleiostemoneus		0.57								
Tetraria octandra	2.57			5.09		2.30				
Unidentified species									0.58	
Total for sedge species	27.43	16.87	6.13	46.44	19.29	23.01		5.83	6.98	4.74
% of total for all plants	18.7	13.3	7.1	14.6	21.1	24.1		13.2	8.1	3.2
Total no. of sedge species	15	14	6	14	12	11	0	3	13	6

The canopy cover provided by sedges and grasses at Site 1 was markedly higher than at other sites (Table 2). Despite the low density of sedges at Site 3, those species present made up 13 2 % of the total canopy cover for this site, an outcome closely related to the fact that sedges occurred in the form of widely-dispersed, large clumps (Table 3). Major producers of nectar and pollen provided relatively little canopy cover at Sites 1, 2 and 3, although they accounted for approximately 32 and 72 %, respectively, of the cover at

Sites 4 and 5 (Table 4). Plant densities for *Banksia grossa* and *B. leptophylla*, in particular, were exceptionally high at Site 4.

Table 4: Density and canopy cover for plants whose pollen was detected on honeyeaters and small mammals.

Plant species	Plant density (plants/100 m2)					Canopy cover (cm2/100 m2)				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
Adenanthos cygnorum	< 0.10		< 1.00	< 0.10	< 0.10					
Astroloma microdonta	1.00	1.57	1.00			0.90				
Banksia attenuata	< 1.00	1.14	1.00	1.82	< 1.00			1.90	2.60	
B. candolleana	< 1.00	1.00	< 0.10	9.45	1.00				7.60	1.10
B. grossa	1.00			31.95	1.00	4.60			7.00	1.40
B. hookerana		1.00	< 1.00	42.18	< 1.00				3.20	
B. leptophylla	< 1.00		1.00	< 1.00	< 1.00			8.00	3.20	
B. lanata	< 1.00	1.00	< 1.00		1.00					12.10
B. menziesii		< 0.10		< 1.00						
Beaufortia elegans	1.29	1.76	12.00	13.89	6.13	0.70		2.80	1.70	3.70
Calothamnus quadrifidus		< 1.00	< 0.10							
C. sanguineus	1.00	1.20	2.00	1.82	1.00	1.80			0.80	2.40
C. cf villosus					1.88					22.30
Calytrix flavescens					< 1.00					
C. daphnoides		< 1.00								
Dryandra falcata	< 1.00		< 1.00							
D. nivea	1.00	1.00	2.00		< 0.10					1.10
D. kippistiana		< 1.00								
D. carlinoides		1.29								
D. shuttleworthiana	1.00	1.85			1.00	3.00				2.00
D. tridentata	1.00			1.82	1.00					0.20
D. tortifolia			1.00		1.00			1.40		
Eucalyptus tetragona	1.00	1.25	1.00			0.80				
E. todtiana		1.00		3.64	< 0.10				4.20	
E. macrocarpa		< 0.10	< 0.10							
Grevillea eriostachya		1.00	< 0.10	< 1.00	< 1.00					
G. shuttleworthiana	1.00				< 1.00	0.10				
Hakea costata		1.00	1.00	1.00	1.33			4.90	0.10	1.20
Isopogon tridens	1.00	2.40	1.00			2.10				
Jacksonia floribunda	1.05	1.14	1.00	4.65	1.00	3.20			1.30	2.00
Lambertia multiflora	1.00	1.20	1.00			1.00				
Melaleuca tricophylla	1.18	2.09				0.20				
Petrophile ericifolia	< 1.00									
Verticordia densiflora	< 0.10		< 0.10	3.31	1.86				0.30	22.90
V. grandis	< 1.00	1.00	< 0.10	< 1.00	< 1.00					
Total for all species	13.52	24.89	24.00	115.5	19.20	18.40		19.00	32.10	72.30
Total number of species	21	24	22	16	21	11		5	11	12

3.3.3 Flowering phenology

At least some major nectar- and pollen- producing species were in flower during each visit to the five sites, although sites varied with respect to the months in which most species flowered (Table 5). For instance, Site 4 had similar numbers of species in flower during most visits, whereas flowering at the other sites was skewed in favour of September or January.

Table 5: Flowering phenology at undisturbed and rehabilitated sites. * denotes month(s) in which peak flowering occurred.

Site	1987			1988		
	July	September	November	January	March	May
1	*D. kippistiana** *V. grandis* *L. multiflora**	*A. cygnorum* *D. aff falcata** *L. multiflora**	*A. cygnorum** *B. attenuata** *B. lanata* *V. grandis*	*A. cygnorum** *B. attenuata* *B. lanata* *B. leptophylla* *E. tetragona** *V. grandis*	*A. cygnorum* *B. leptophylla** *E. tetragona* *V. grandis*	*B. candolleana** *B. leptophylla** *C. sanguineus*
2	*B. hookeriana** *B. menziesii* *C. daphnoides** *L. multiflora*	*B. hookeriana* *D. carlinoides** *G. eriostachya** *C. quadrifidus** *E. macrocarpa* *L. multiflora*	*B. attenuata** *B. lanata** *G. eriostachya* *C. quadrifidus*	*B. attenuata* *B. lanata* *G. eriostachya*	*B. hookeriana* *G. eriostachya*	*B. hookeriana** *B. menziesii*
3	*B. hookeriana** *C. sanguineus* *E. macrocarpa* *V. grandis* *L. multiflora*	*A. cygnorum* *B. hookeriana* *D. aff falcata** *G. eriostachya* *E. macrocarpa* *M. tricophylla** *V. grandis* *L. multiflora**	*A. cygnorum** *B. attenuata** *B. lanata** *G. eriostachya** *E. macrocarpa** *V. grandis*	*A. cygnorum* *B. attenuata** *B. lanata* *G. eriostachya* *E. macrocarpa** *V. grandis**	*A. cygnorum* *B. leptophylla* *G. eriostachya* *V. grandis*	*B. hookeriana* *B. leptophylla** *C. sanguineus**
4	*B. hookeriana* *B. leptophylla* *B. menziesii* *C. sanguineus*	*A. cygnorum* *B. hookeriana** *G. eriostachya* *V. grandis*	*A. cygnorum* *G. eriostachya* *V. grandis*	*A. cygnorum* *G. eriostachya* *E. todtiana** *V. grandis*	*B. hookeriana* *B. leptophylla* *V. grandis*	*B. candolleana** *B. hookeriana** *B. leptophylla* *B. menziesii** *C. sanguineus*
5	*B. leptophylla** *G. shuttleworthiana** *C. sanguineus* *V. grandis*	*A. cygnorum* *G. eriostachya* *C. villosus* *V. grandis*	*A. cygnorum* *B. attenuata** *B. lanata* *C. villosus* *V. grandis*	*A. cygnorum* *B. attenuata* *B. lanata* *B. leptophylla* *G. eriostachya* *C. flavescens** *E. todtiana** *V. grandis*	*B. leptophylla* *V. grandis*	*B. candolleana** *B. leptophylla* *C. sanguineus*

3.4 Discussion

Rehabilitation of mined land is unlikely to establish vegetation in exactly the form that it took prior to mining. Nevertheless, vegetation which approximates that in surrounding areas is likely to function in a manner similar to undisturbed ecosystems within the region. For this reason, comparisons between vegetation in natural and rehabilitated sites are frequently made when assessing the success or otherwise of rehabilitation techniques.

3.4.1 <u>The possible effects of low leaf litter and large areas of bare ground</u>

Major differences between the vegetation in natural and rehabilitated sites observed in this study were the occurrence in the latter of large areas of bare ground, caused by low leaf litter and canopy cover, low canopy cover and density of sedges and a low plant species diversity. Areas of bare ground occur naturally within kwongan heath, as observed at Sites 1 and 4, and may be used for foraging by reptiles. However, these areas tend to be small and scattered amongst the vegetation. Large bare patches of the type seen at Sites 3 and 2, prior to mulching in 1987, may have reduced overall opportunities for feeding and/or sheltering from predators by mammals, reptiles and birds.

Leaf litter provides a habitat for invertebrates and the soil micro flora and fauna. Interaction between leaf litter and the soil contributes to the structure, water retention properties and nutrient recycling of soils. Leaf litter is also likely to reduce the surface soil temperatures during the hot dry summer months. Plant density and canopy cover have a positive effect on leaf litter cover, with litter tending to persist mainly in areas around or under plants. Mulching therefore becomes an important technique in the early stages of rehabilitating sites after mining until a reasonable density and canopy cover of plants is established. Site 2, revisited in October 1990, showed that leaf litter had persisted within areas of established plants and seedlings. This result contrasts with that observed at the same site in 1987, where the effect of effect of mulching in 1984 had largely been lost.

3.4.2 Possible causes of poor establishment of sedges and grasses at rehabilitated sites

The poor establishment of species from the families Restionaceae and Cyperaceae has been recognised by RGC, and attributed to a shortage of seed in the topsoil and low viability of sown seed (Brooks & Jefferies 1990). Research by Meney & Dixon (1988) on selected species has also indicated that these species tend to sustain themselves within natural vegetation by vegetative growth rather than sexual reproduction. Seed production is reduced by unfavourable weather conditions, and in cases where seeds develop viable embryos, inhibitory mechanisms within the endosperm often prevent germination.

The significance of sedge species to fauna occurring within kwongan heath is largely unknown. Being a significant component of this heath, however, it is important that they are re-established with similar densities and diversities as found on natural sites.

3.4.3 Plant species diversity at natural and rehabilitated sites

Rehabilitation techniques have improved since Site 3 was rehabilitated in 1977, and Site 2 in 1982. Current techniques increase the diversity of plant species and canopy cover at rehabilitated sites, and include the replacement of top soil (which holds stored seed), mulching (a source of seed and leaf litter), direct seeding for a range of species collected by hand, and the planting of seedlings raised from seeds or cuttings (Brooks 1989; O'Grady 1990). Different types of plants often need different conditions or means to establish in new areas. Those species most difficult to establish under current techniques are those that tend to reproduce vegetatively, e.g., some sedge species.

The three natural sites observed during this study had vegetation whose structure and species composition were slightly different. These variations are further illustrations of the diversity that occurs between kwongan sites as well as within sites (Hopkins & Hnatiuk 1981). While the locations of the rehabilitated sites suggest that they should have developed characteristics that approached those of Site 1, significant differences were apparent. Changes in the soils at these sites may have been partly responsible for differences in vegetation structure and composition, although the restricted range of seed and seedlings introduced to sites using current rehabilitation techniques may have limited plant species diversity to a far greater extent.

Observations made at the five sites involved in this study indicate that plant species richness, density and canopy cover alone do not provide an adequate basis for the comparison of these sites. Sites can also vary with regard to the form taken by different plant species. For instance, plant height and diameter can vary, thus producing a different vegetation structure.

3.4.4 Other factors that differ between rehabilitated and natural sites

Rehabilitated Sites 2 and 3 experienced surface flooding and flooding of pitfall traps in July 1987 (Figures 10 and 11). The soil at these two sites tended to have a high clay content, producing a hard baked crust in the summer and 'sticky' soil in the winter months. Although some flooding of pitfalls was experienced at the natural sites, only a few centimetres of water, if any, accumulated in the bottom of the pitfalls. These observations indicate that there is poor drainage at the rehabilitated sites which could adversely affect the use of these sites by vertebrates. The mining process itself effects changes in the geology of a site, changing the hydrology and soil composition. These factors may need to be addressed before rehabilitation can be fully successful with respect to supporting the local fauna (see Chapter 4).

3.4.5 Flowering phenology and plant size

The high diversity of plants within kwongan heath means that several species flower at the same time and there will be one or more plant species in flower at most times of the year. Rehabilitated sites need to be able to provide a similar variety of flowering and

Figure 10: Surface water at rehabilitated Site 3 in July 1988.

Figure 11: Flooded pitfall trap at rehabilitated Site 2 in July 1988.

seeding species throughout the year if local fauna are to be supported. Low food availability at certain times will determine whether individual species can survive in these areas throughout the year, and whether critical population sizes can be maintained on a long-term basis. These matters are discussed in detail in Chapter 4 of this report.

Due to high species diversity, the diameter of individual plants in kwongan heath studied at Sites 1, 4 and 5 tended to be relatively small. In contrast, rehabilitated Sites 2 and 3 comprised many large, spreading plants that were major producers of nectar. In particular, *Adenanthos cygnorum* and *Calothamnus sanguineus* bushes at Site 3 (Figure 12) were much larger than those at the natural sites. It is suggested that these differences are at least partly due to the initial low seedling establishment at rehabilitated sites, with consequently reduced competition for resources such as water, nutrients and space at those locations.

Figure 12: Relatively large *Calothamnus sanguineus* plant located at rehabilitated Site 3.

4. Vertebrate Fauna

4.1 Introduction

The incidence and abundance of fauna are influenced by environmental factors such as topography, soil and vegetation. Of particular importance to the continued survival of various species are the provision of appropriate shelter, nesting materials and food resources (Collins *et al.* 1985; Nichols *et al.* 1989). Interactions between species will also have an effect on their relative abundance (Twigg *et al.* 1989). In the longer term, changes in weather patterns or climate, e.g., periods of drought or very wet years, or a trend towards increasing aridity with a decreasing rainfall and increasing temperatures, will place heavy demands on biota, especially plant species and local fauna that are relatively sedentary.

The occurrence of particular species has been used as a measure of the success of rehabilitation techniques (Nichols *et al.* 1989). Their relative abundance, and occurrence from month to month and from year to year, need to be determined. While some species are 'generalists' and therefore able to use a range of habitats for shelter, nesting or food, other species are more specialised and rely on the presence of particular resources or habitats. It is the more specialised species that often give an indication of a habitat or microhabitat that is missing from the rehabilitated sites yet is present in undisturbed ecosystems.

In this chapter, the presence and relative abundance of mammal, reptile, frog and bird species detected at each of the five study sites are described. Differences between sites are related to the biology of the species involved, with particular reference made to the mobility, preferences for shelter and breeding patterns of these species.

4.2 Methods

4.2.1 Presence and relative abundance of vertebrate species at each site

4.2.1.1 *Reptiles, frogs and mammals*

The presence and relative abundance of mammals, reptiles and frogs were determined by trapping animals in pitfall (hereafter referred to as pitfalls) and Elliott (box) traps. Animals captured were individually marked and released. Mammals were marked by ear clipping, and reptiles and frogs by toe clipping. Recaptured animals were identified and movements between sites recorded. Trapping was conducted during bi-monthly field trips from July 1987 to September 1988. Capture rates for the months of July and September were compared between 1987 and 1988.

A combination of pitfalls and box traps were used to ensure that most species in the area would be caught. A grid of 40 pitfalls (five rows of eight pitfalls, each 10m apart) was installed at each site in June 1987. Pitfalls were made of PVC pipe, 11 cm diameter, 40 cm deep, with flywire mesh attached to the bottom end to allow water run off and yet prevent animals from burrowing out. No drift-lines were used within these grids. In November 1987, four larger pitfalls (plastic buckets 28 cm in diameter and 40 cm deep with perforations in the base) were placed 10m apart along a 30 m transect at each site, with a 30 cm high, seven metre long, drift-line fence bisecting each trap. Four box traps were also used at each site during surveys from November 1987 to September 1988. These were baited with a mixture of peanut butter, rolled oats and raisins (Fox & Posamentier 1976; Read 1985).

Pitfalls were opened over seven nights during each field trip other than in July and September 1988, when traps were only opened for three consecutive nights. Due to the tendency for capture rates to fall off after three to four nights (Collins, pers. comm.), traps were initially opened for four consecutive nights then closed for approximately five nights before re-opening them for a further three nights. Within each field trip, traps were opened alternately at two groups of sites (pitfalls were either open simultaneously at Sites 1 and 2 or at Sites 3, 4 and 5). This regime worked well throughout the study period with very few fatalities recorded.

As each site was sampled in the same way, it was possible to compare results for those sites. Mammal, reptile and frog abundances were expressed as the numbers captured per trapping night for each sampling period (either seven or three trapping nights). Individuals retrapped between sampling periods were included in this figure, while individuals retrapped within sampling periods were not.

4.2.1.2 *Birds*

To obtain a seasonal census of bird densities at each of the five sites, two 70-metre transects were established in close proximity to the pitfall grids at each site. These were walked at dawn, midday and dusk (or as close to these times as possible) four times at each site during each field trip. Birds within 20m either side of the transect were identified and counted with the aid of binoculars, and data recorded on a small, voice-activated tape recorder. Transects at Sites 1 and 2 were conducted on the same day, as were Sites 3, 4 and 5. A total of 0.56 ha (2 x 40 m x 70 m = 5,600 m^2) were censused per site four times during each field trip. Bird densities were expressed as the mean number of birds per ha.

Birds were also trapped using two mistnets for a total of six to eight hours at each site during each field trip. Birds caught were banded with Australian National Parks and Wildlife Service aluminium bands bearing individual numbers. These numbers were used to identify individual birds when recaught. Measurements such as the weight, total head length and wing length of these birds were also taken (Lowe 1989).

4.2.2 Breeding activity and population structure of vertebrate species

4.2.2.1 *Reptiles, frogs and mammals*

Adult and juvenile animals were distinguished by their size and weight. Snout-vent lengths (SVL's) were recorded for this purpose for reptiles and frogs, and body lengths and weights for mammals. These data were compared with data collected from other studies that established maturity and breeding condition following dissections (e.g., Kitchener & Chapman 1978; Chapman & Dell 1978, 1980; Dell & Chapman 1979a, b; Murray 1980). The presence of pouch young and incidence of lactating females were also recorded as evidence of breeding activity for two marsupial species.

4.2.2.2 *Birds*

In the case of honeyeaters, juvenile birds trapped in mist-nets were distinguished from adults on the basis of either plumage and soft part features, or by comparing wing lengths with total head-bill lengths. Wing lengths tend to increase in size when juveniles moult their primaries at six to eighteen months (Congreve 1992). Juveniles, therefore, would be expected to have smaller wing lengths than adults of comparable size. Evidence of nesting activity was collected opportunistically.

4.3 Results

Fourteen species of reptile, seven species of frog and four species of mammal were trapped at the five sites during the study (Table 6). While mammal species were trapped throughout the year, reptiles were trapped during the spring, summer and autumn surveys, and frogs during autumn, winter and spring (Table 7: Figures 13-15). Twenty three species of bird were observed at the five sites (Table 8), and four species of honeyeaters (134 birds) banded from July 1987 to May 1988 (Figure 16).

Table 6: Vertebrates captured per trapping night at each site from July 1987 to September 1988.

	Site 1	Site 2	Site 3	Site 4	Site 5	Total trapped	Number of recaptures
FROGS							
Heleioporus albopunctatus	0.6	0.4	0.6	0.8	1.3	23	2
Heleioporus eyrei	0.6	0	0.1	3.7	9.6	59	0
Limnodynastes dorsalis	0.1	0.3	0.1	0.1	0.3	6	0
Myobatrachus gouldii	0.1	0	0	0	0.3	2	0
Neobatrachus pelobatoides	2.3	1.4	2.9	4.8	3.0	77	0
Pseudophryne guentheri	0.3	0.5	0.6	2.2	6.4	69	1
Frog sp.						1	0
TOTAL NUMBER OF FROGS TRAPPED						**244**	3
REPTILES							
Skinks							
Ctenotus fallens	0.6	0	0	1.0	0.3	13	0
Ctenotus pantherinus	0	0	0.1	0.1	0	2	0
Ctenotus schomburgkii	0	0	0.1	0.9	0.7	13	0
Lerista praepedita	0	0	0	0	0	1	0
Tiliqua rugosa	0.1	0.3	0	0	0	2	0
Dragons							
Ctenophorus maculatus	0.3	0	0.1	0	0.9	9	0
Pogona minor	1.8	0.1	0	0.3	0.1	13	0
Tympanocryptis adelaidensis	0	0	0	3.5	1.3	28	0
Geckos							
Diplodactylus spinigerus	1.2	1.1	1.4	0.9	0.3	33	0
Gecko sp	0	0	0.3	0	0	2	0
Legless lizard							
Lialis burtonis	0	0	0	HC	0	1	0
Snakes							
Notechis curtis	0	0	0.1	0	0	1	0
Rhinoplocephalus gouldii	0.1	0	0	0	0	1	0
Vermicella littoralis	0	0	0	0	0.1	1	0
TOTAL NUMBER OF REPTILES TRAPPED						**126**	**0**
MAMMALS							
Mus musculus	6.1	5.0	3.6	4.0	8.7	161	7
Pseudomys albocinereus	1.6	0.1	0.1	5.6	1.7	56	12
Sminthopsis granulipes	2.3	0	0	1.5	0.4	30	7
Tarsipes rostratus	2.5	0.7	0.6	5.2	4.0	81	2
TOTAL NUMBER OF MAMMALS TRAPPED						**328**	**28**

HC = one individual hand caught at Site 4
Recaptures = only those recaptured between survey months

4.3.1 <u>Comparison of reptile, frog and mammal captures in 1987 and 1988</u>

In July and September of 1987, 40 small pitfalls were opened for seven nights at each site, while in 1988 four large pitfalls and four box traps were used in addition to the 40 small pitfalls, and traps were opened for only three nights. In the following section, comparisons for July and September in 1987 and 1988 are made using only those vertebrates trapped in the 40 small pitfalls and after expressing captures as the number of animals caught per trapping night. Comments are also made on the effect that large pitfalls and box traps appeared to have on trapping rates for different species.

Table 7: Vertebrates captured per trapping night each month from July 1987 to September 1988.

	1987					1988			Total	Number of
	July	Sept	Nov	Jan	Mar	May	July	Sept	trapped	recaptures
FROGS										
Heleioporus albopunctatus	0.7	0.4	0.3	0.0	0.3	1.3	0.3	0.3	23	2
Heleioporus eyrei	0.4	0.4	0.6	0.0	0.4	2.4	0.3	9.3	59	0
Limnodynastes dorsalis	0.3	0	0	0	0	0.4	0.3	0	6	0
Myobatrachus gouldii	0	0	0	0	0	0.1	0	0.3	2	0
Neobatrachus pelobatoides	4.0	0	0	0	0	4.6	4.7	1.0	77	0
Pseudophryne guentheri	1.0	1.7	0.3	0	0	2.3	3.3	7.7	69	1
Frog sp.									1	0
TOTAL NUMBER OF FROGS TRAPPED									**244**	**3**
REPTILES										
Skinks										
Ctenotus fallens	0	0.1	0.3	1.0	0.4	0	0	0	13	0
Ctenotus pantherinus	0	0	0	0.1	0.1	0	0	0	2	0
Ctenotus schomburgkii	0	0	0.6	0.4	0.7	0	0	0.3	13	0
Lerista praepedita	0	0	0	0	0.1	0	0	0	1	0
Tiliqua rugosa	0	0	0.1	0	0	0	0	0.3	2	0
Dragons										
Ctenophorus maculatus	0	0.4	0.1	0	0.7	0	0	0	9	0
Pogona minor	0.1	0.1	0.6	0.1	0.7	0	0	0.7	13	0
Tympanocryptis adelaidensis	0	0.1	1.3	0.7	0.9	0.4	0	0.6	28	0
Geckos										
Diplodactylus spinigerus	0	1.6	1.7	1.7	0.3	0.3	0	0.3	33	0
Gecko sp	0	0.1	0.1	0	0	0	0	0	2	0
Legless lizard										
Lialis burtonis	0	0	HC	0	0	0	0	0	1	0
Snakes										
Notechis curtis	0	0	0	0	0.1	0	0	0	1	0
Rhinoplocephalus gouldii	0	0	0	0.1	0	0	0	0	1	0
Vermicella littoralis	0	0	0.1	0	0	0	0	0	1	0
TOTAL NUMBER OF REPTILES TRAPPED									**126**	**0**
MAMMALS										
Mus musculus	2.3	2.0	5.1	3.6	2.6	3.4	5.0	4.3	161	7
Pseudomys albocinereus	1.4	1.7	1.9	1.0	0.4	0.7	1.3	0.7	56	12
Sminthopsis granulipes	0.6	0.1	1.6	0.6	0.6	0.6	0.7	0	30	7
Tarsipes rostratus	0.9	0.9	2.4	3.1	2.0	0.4	1.7	2.7	81	2
TOTAL NUMBER OF MAMMALS TRAPPED									**328**	**28**

HC = one individual hand caught at Site 4
Recaptures = only those recaptured between survey months

(a)

(b)

(c)

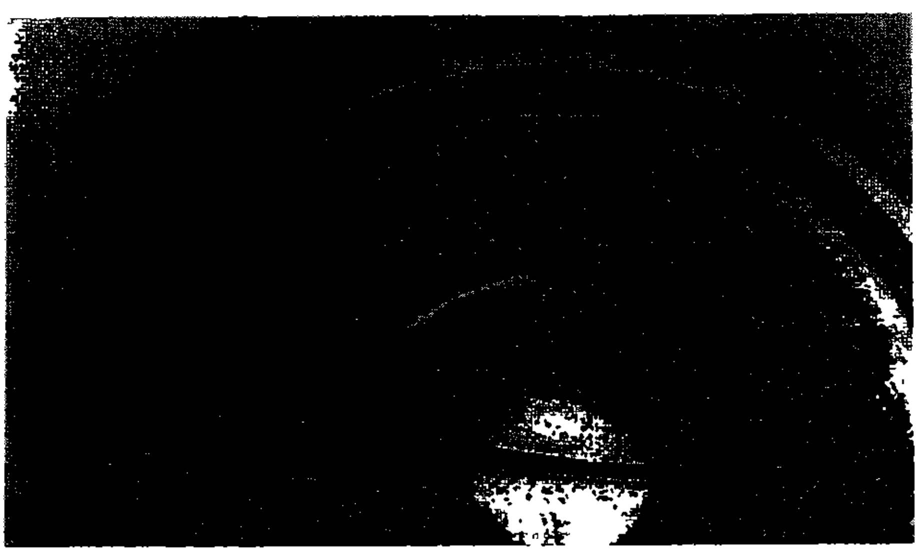

Figure 13: Some of the reptiles captured at the study sites (a) *Diplodactylus spinigerus*, (b) *Tiliqua rugosa* and (c) *Pogona minor*.

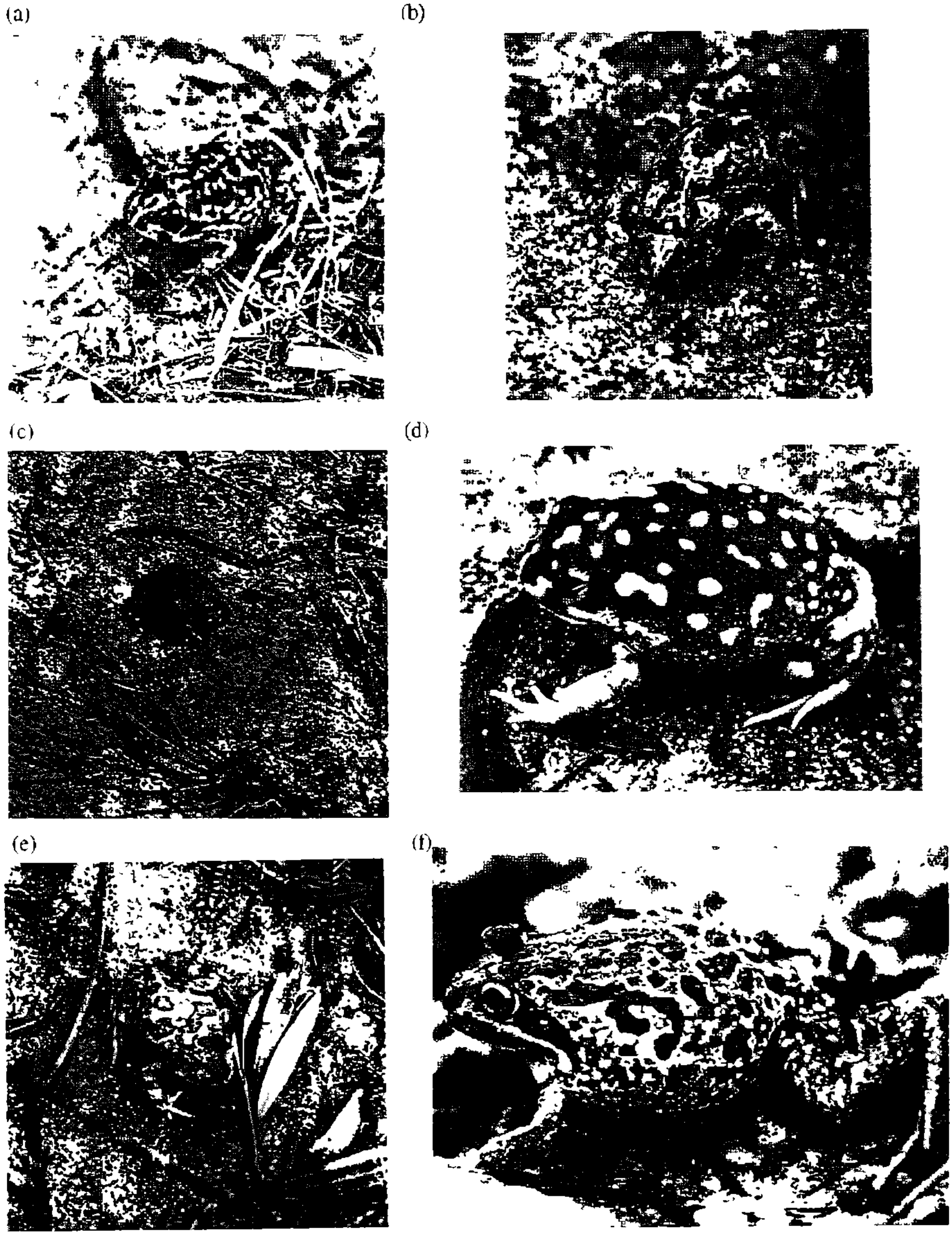

Figure 14: Some of the frogs captured at the study sites (a) *Heleioporus eyrei*, (b) *Pseudophryne guentheri*, (c) *Myobatrachus gouldii*, (d) *Heleioporus albopunctatus*, (e) *Neobatrachus pelobatoides*, (f) *Limnodynastes dorsalis*.

(a)

(b)

(c)

Figure 15: Southwestern Australian endemic mammals captured at the study sites (a) *Tarsipes rostratus*, (b) *Sminthopsis granulipes* and (c) *Pseudomys albocinereus*.

Table 8: Abundance (birds/0.56 ha) of birds recorded at each of the five sites from September 1987 to July 1988.

	Site 1	Site 2	Site 3	Site 4	Site 5
Honeyeaters					
Anthochaera carunculata			0.02		
Lichenostomus virescens			x		
Lichmera indistincta	0.30	0.27	1.61	0.15	0.45
Phylidonyris melanops	1.19	0.15	2.08	0.18	0.20
Phylidonyris nigra	0.77	1.51	2.78	2.21	1.54
Fairy-wrens					
Malurus lamberti	0.05			0.10	x
Malurus leucopterus	0.50	0.27	0.02	0.10	
Malurus splendens	0.02				
Calamanthus					
Sericornis fuliginosus	0.02		0.40		
Fantail and Wagtail					
Rhipidura fuliginosa			X		
Rhipidura leucophrys	x	x	0.28		
Robin					
Petroica goodenovii					0.02
Pigeons					
Ocyphaps lophotes	x				
Phaps chalcoptera/elegans	0.02	0.05	0.18	0.10	
Cockatoos					
Cacatua roseicapilla	0.17	0.15		0.22	0.10
Calyptorhynchus baudinii			0.05		
Cuckoo					
Chrysococcyx basalis			x		
Pipit					
Anthus novaeseelandiae	x	0.1	0.08		
Swallows					
Cheramoeca leucosternum	0.15	0.08	0.02		0.55
Hirundo neoxena	x	x	0.1	x	x
Woodswallow					
Artamus cinereus			0.25		
Raven					
Corvus coronoides	0.02	0.1	0.12		0.05
Kite					
Elanus notatus		0.05			
TOTAL NUMBER OF SPECIES	**15**	**12**	**17**	**8**	**9**

x = species observed at the sites but not counted during any census

4.3.1.1 *Reptiles*

In July 1987 and 1988, capture rates for reptiles in small pitfalls were very low, with only one *Pogona minor* trapped in 1987 and no reptiles in 1988 (Figure 17). Rates were higher in September, especially for *Diplodactylus spinigerus* (Western Spiny-tailed Gecko) and *Ctenophorus maculatus* (Spotted Dragon) in 1987, and two dragon species (*Pogona minor* and *Tympanocryptis adelaidensis*) in 1988.

(a)

(b)

(c)

Figure 16: Honeyeaters captured at the study sites (a) *Lichmera indistincta*, (b) *Phylidonyris nigra*, (c) *Phylidonyris melanops*.

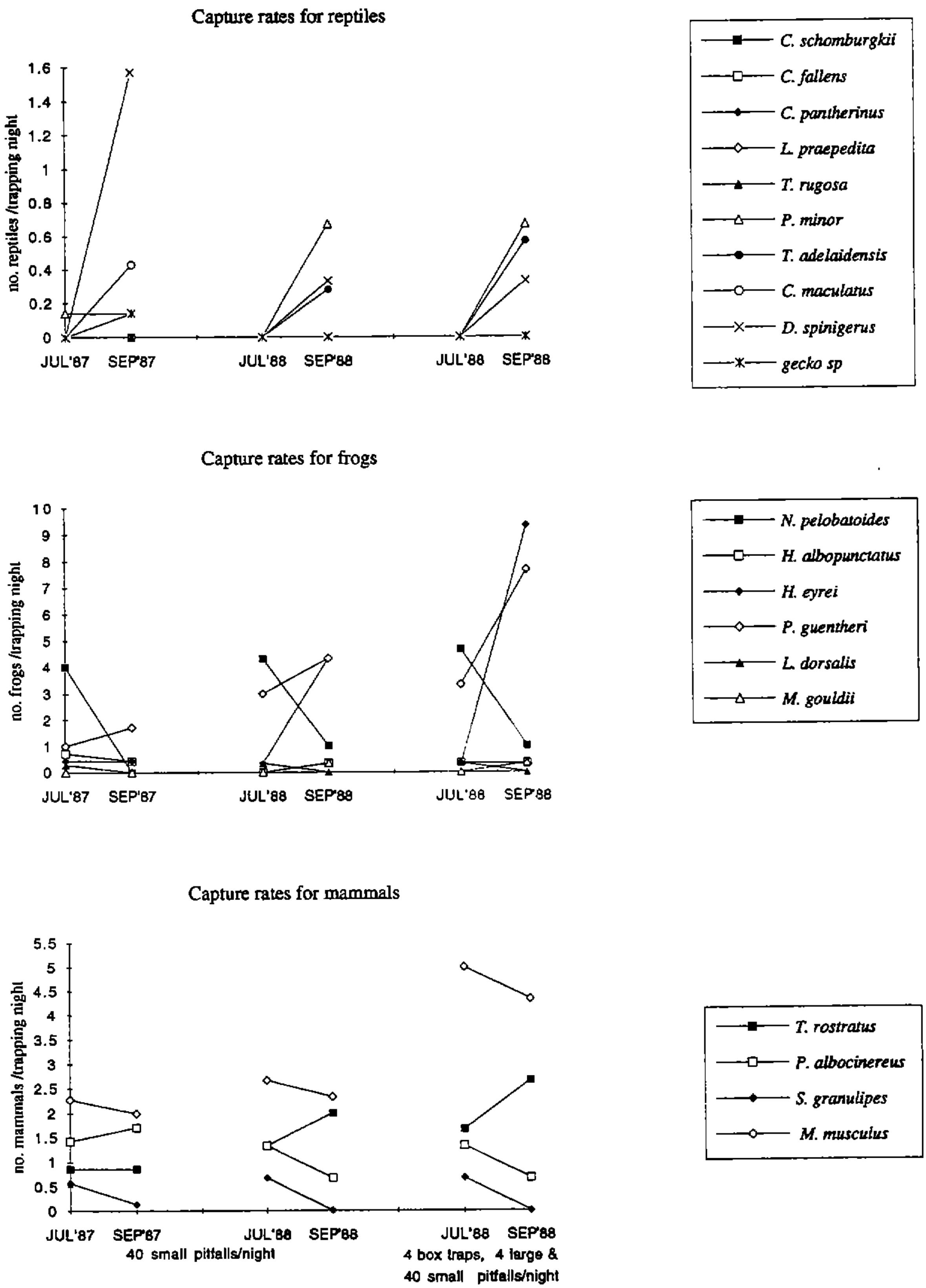

Figure 17: Capture rates for reptiles, frogs and mammals in July and September of 1987 and 1988; small pitfalls were used in 1987, and both box traps, and small and large pitfalls in 1988

4.3.1.2 *Frogs*

Frogs were captured in small pitfalls at similar overall rates in July of 1987 and 1988, although a greater number of species were trapped in 1987, and *Pseudophryne guentheri* (Guenther's Toadlet) was trapped at a higher rate in 1988 (Figure 17). Rates were higher for *P. guentheri* and *Heleioporus eyrei* (Moaning Frog) in September 1988 than at the corresponding time in 1987.

Large pitfalls almost doubled the number of individuals trapped for both of the above mentioned species in September 1988, while having no effect on the numbers of other species captured (Figure 17). This contrasted with July 1988, when the large pitfalls trapped only low numbers of frogs (four out of a total of 27 frogs caught).

4.3.1.3 *Mammals*

Trapping rates for *Mus musculus* (House Mouse) and *Sminthopsis granulipes* (White-tailed Dunnart) in small pitfalls were similar between years in July and September (Figure 17). In September 1988, however, there was an increase in the capture rate for *Tarsipes rostratus* (Honey Possum), and a decrease in the capture rate of *Pseudomys albocinereus* (Ash-grey Mouse) compared with September 1987.

The large pitfalls and box traps did not influence trapping rates for *S. granulipes* or *P. albocinereus* (Figure 17), although they greatly increased rates for *M. musculus* and contributed small additional numbers of *T. rostratus*.

4.3.2 Relative abundance of reptiles, frogs and mammals at each site

Data presented in this section include capture rates from all traps used and are expressed as the number of animals caught per trapping night. Since July and September 1987 differed from all other survey months, in that no large pitfalls or box traps were open, the following considerations need to be kept in mind when comparing capture rates for July and September 1987 with those for other survey months. Firstly, the large pitfalls were significant in that they trapped the larger reptiles such as *P. minor* and *T. adelaidensis* (both dragon species), and box traps were the only traps to catch *Tiliqua rugosa* (Bobtail Lizard). Secondly, the large pitfalls significantly increased the number of two frog species (*H. eyrei* and *P. guentheri*) when these species were abundant, e.g., in May and September 1988. Thirdly, both box traps and large pitfalls increased the number of *M. musculus* captured during each of the survey months.

Capture rates at rehabilitated and undisturbed sites were compared using a Chi squared Goodness of Fit Test. As the trapping effort was the same at each site (two of which were rehabilitated and three of which were undisturbed), 2/5 of captures for any particular species might have been expected to occur at rehabilitated sites.

4.3.2.1 *Reptiles*

Reptiles were most active during the spring and summer surveys. The most commonly trapped reptile species were (in descending order): *D. spinigerus*, *T. adelaidensis*, *Ctenotus fallens* (skink) *C. schomburgkii* (skink), *P. minor* and *C. maculatus*. Capture rates for reptiles were highest at undisturbed Sites 4 and 5, and lowest at rehabilitated Sites 2 and 3 (Figure 18). At Site 2, only three species of reptile, *D. spinigerus* , *P. minor* and *T. rugosa*, were trapped compared to six to eight species at the other sites (Table 6).

Species noticeably absent from the rehabilitated sites were *C. fallens* and *T. adelaidensis*. Overall, both small skink species and dragon species were poorly represented at the rehabilitated sites. In contrast, *D. spinigerus* was present at all sites, although not significantly less or more abundant at any of the sites (Chi squared goodness of fit test $\chi^2 = 5.01$: $0.05 < P < 0.1$), and capture rates were only high in September and November 1987.

The occurrence and abundance of dragon and small skinks varied considerably at the three undisturbed sites. Among the dragon species, *T. adelaidensis* was trapped in highest numbers at Site 4, but not trapped at all at Site 1, while *P. minor* was trapped in highest numbers at Site 1 and *C. maculatus* in highest numbers at Site 5 (not trapped at all at Site 4). Among the small skinks, *C. schomburgkii* was not trapped at Site 1 and *C. fallens* was trapped in highest numbers at Site 4.

Snakes were trapped in very low numbers, with one *Vermicella littoralis* (West Coast Banded Snake) captured in November at Site 5, one *Rhinoplocephalus gouldii* (Gould's Snake) in January at Site 1 and one *Notechis curtis* (Bardick) in March at Site 3. No snakes or other reptiles were recaptured.

4.3.2.2 *Frogs*

Three frog species, *Neobatrachus pelobatoides* (Humming Frog), *H. eyrei* and *P. guentheri* were trapped in high numbers during this study (Figure 19). Capture rates for frogs were highest at the undisturbed Sites 4 and 5. The rehabilitated Site 2 had the lowest

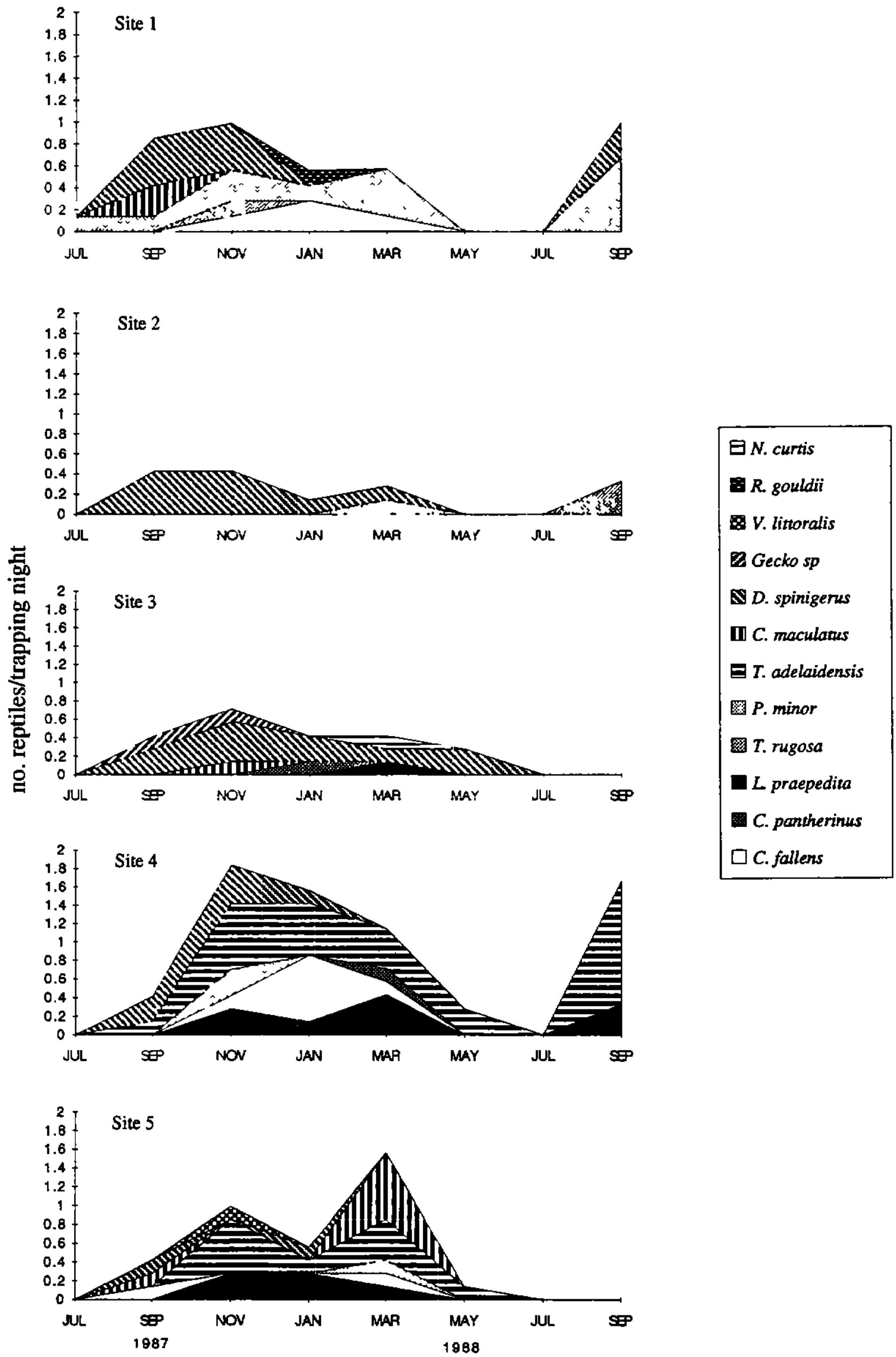

Figure 18: Capture rates for reptiles at each site between July 1987 and September 1988

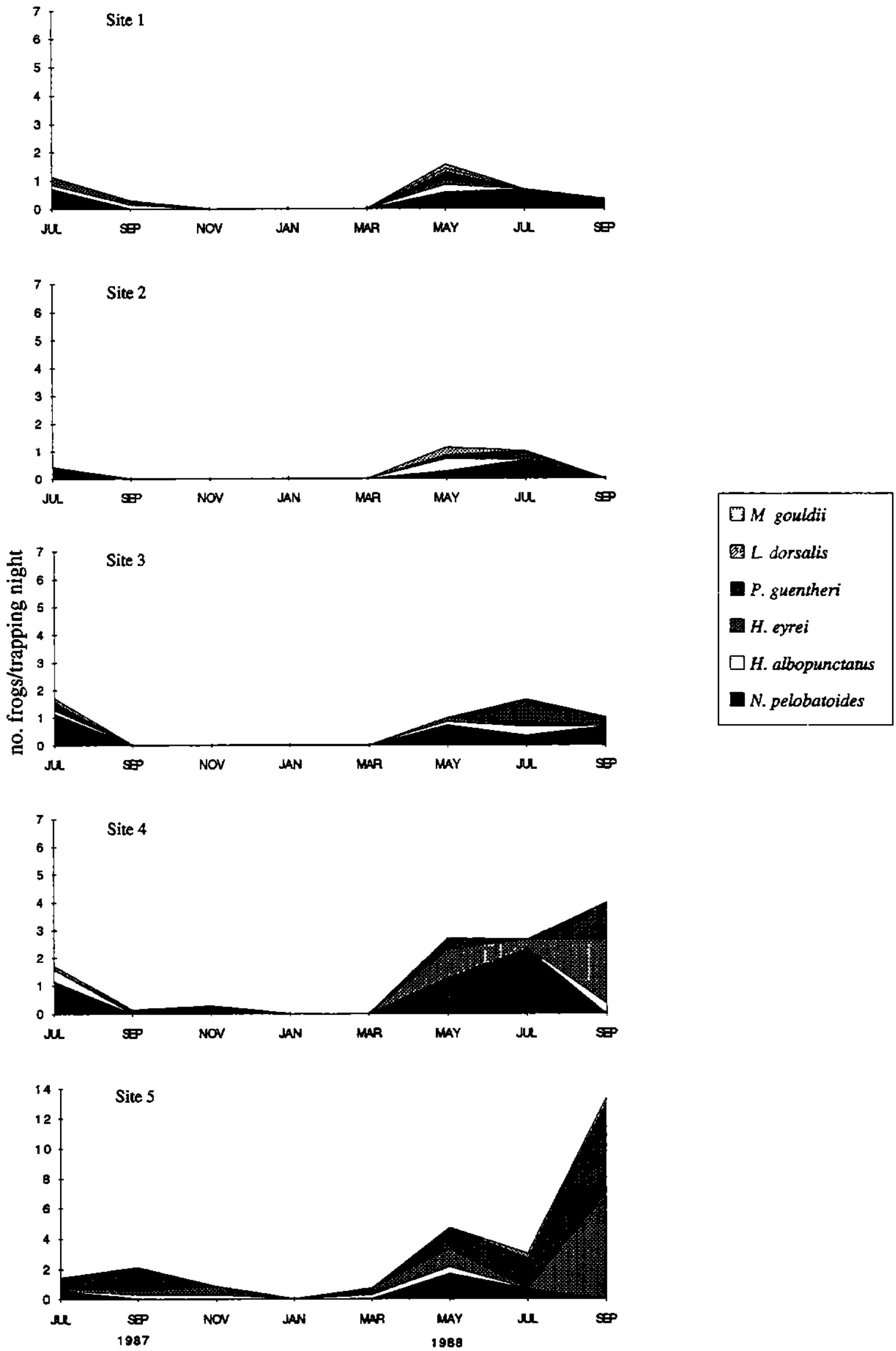

Figure 19: Capture rates for frogs at each site between July 1987 and September 1988. The vertical scale used for Site 5 differs from that for other sites.

rate of frog captures, while capture rates for rehabilitated Site 3 was very similar to those at undisturbed Site 1. The most noticeable difference between undisturbed and rehabilitated sites was the low capture rate or absence of *H. eyrei* at the latter.

Within the three undisturbed sites, *H. eyrei* and *P. guentheri* were trapped in higher numbers than expected at Site 5 and in lower numbers than expected at Site 1 (*P. guentheri*, χ^2 = 63.99, P < 0.001; *H. eyrei*, χ^2 = 33.15, P < 0.001). *Heleioporus albopunctatus* (Burrowing Frog), *Limnodynastes dorsalis* (Banjo Frog) and *Myobatrachus gouldii* (Turtle Frog) were trapped in low numbers. Only two *H. eyrei* and one *P. guentheri*. were recaptured, all three having moved within sites.

4.3.2.3 *Mammals*

T. rostratus and *P. albocinereus* were trapped in significantly higher numbers at undisturbed sites than at rehabilitated sites (*T. rostratus* χ^2 = 13.83, P < 0.001; *P. albocinereus* χ^2 = 30.97, P < 0.001). *T. rostratus* was only captured at rehabilitated sites in November, January and March, and *P. albocinereus* at the rehabilitated sites in November. *S. granulipes* was not trapped at the rehabilitated sites. *M. musculus* was trapped in comparable numbers at the undisturbed and rehabilitated sites (χ^2 = 2.59; 0.1 < P < 0.25) (Table 6, Figure 20).

Overall capture rates for *M. musculus* were higher than those for *P. albocinereus* in all survey months (Figure 21). At Site 4, however, rates for the two species were very similar. Capture rates for *M. musculus* at rehabilitated and undisturbed sites were similar during November to March, but lower at rehabilitated sites during May, July and September (Figure 22).

The numbers of *T. rostratus* trapped at the three undisturbed sites were not significantly different (χ^2 = 5.01, 0.05 < P < 0.1), although animals were more consistently present at Site 4. Significantly greater numbers of *P. albocinereus* were trapped at Site 4 (χ^2 = 21.44, P < 0.001), and significantly more *S. granulipes* at Site 1 (χ^2 = 11.4, 0.001 < P < 0.005).

Overall, peak population size attained appeared to be consistent for *M. musculus* and *T. rostratus*, as similar peak capture rates were obtained throughout the eight surveys (capture rates in July and September were low for *M. musculus* due to the fact that only small pitfalls were used). Capture rates for *S. granulipes* were very similar throughout the eight surveys, except in September (when the males die) and November (when young were active), suggesting very stable population sizes at undisturbed sites. Rates for *P.*

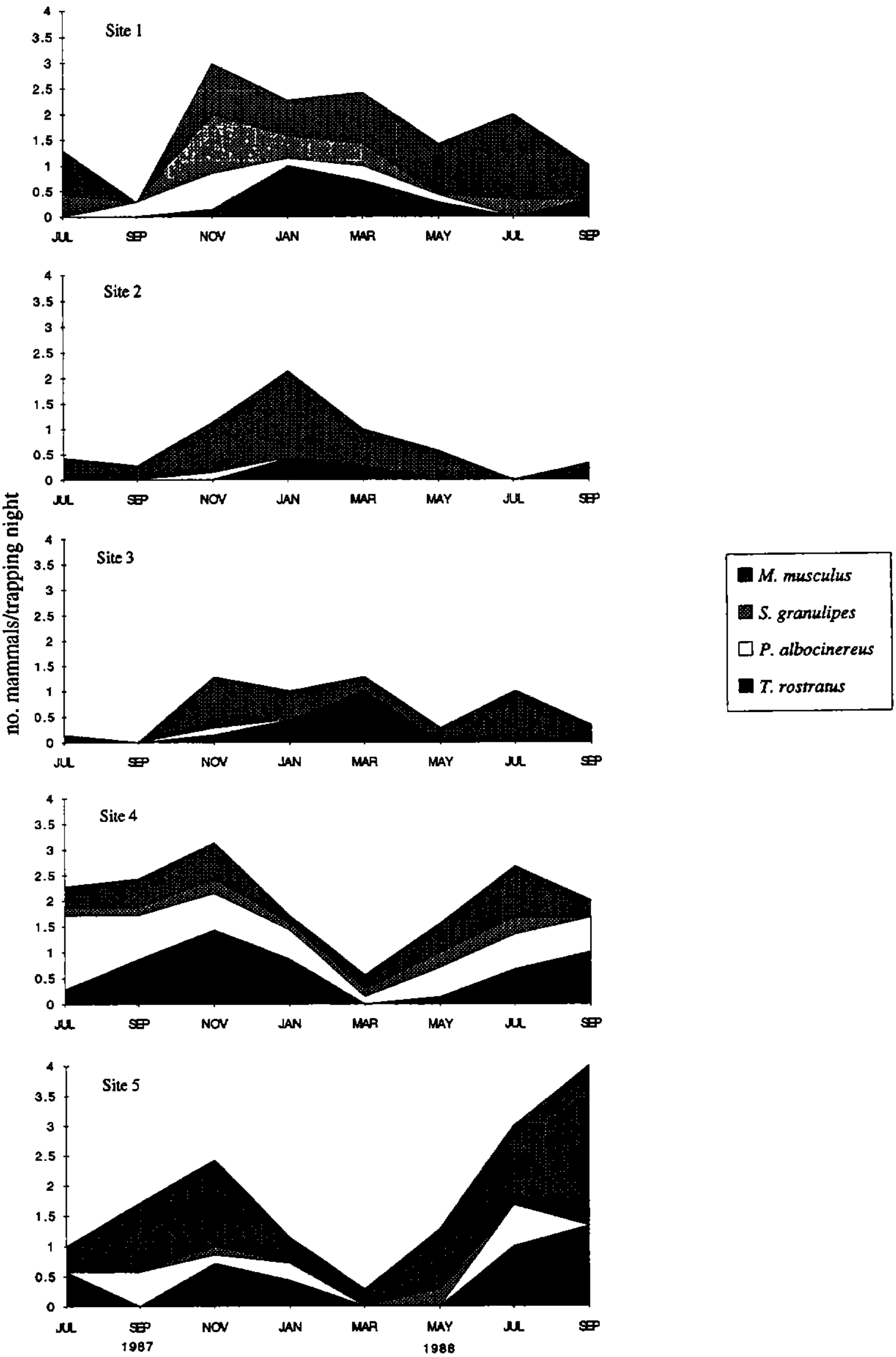

Figure 20: Capture rates for mammals at each site between July 1987 and September 1988

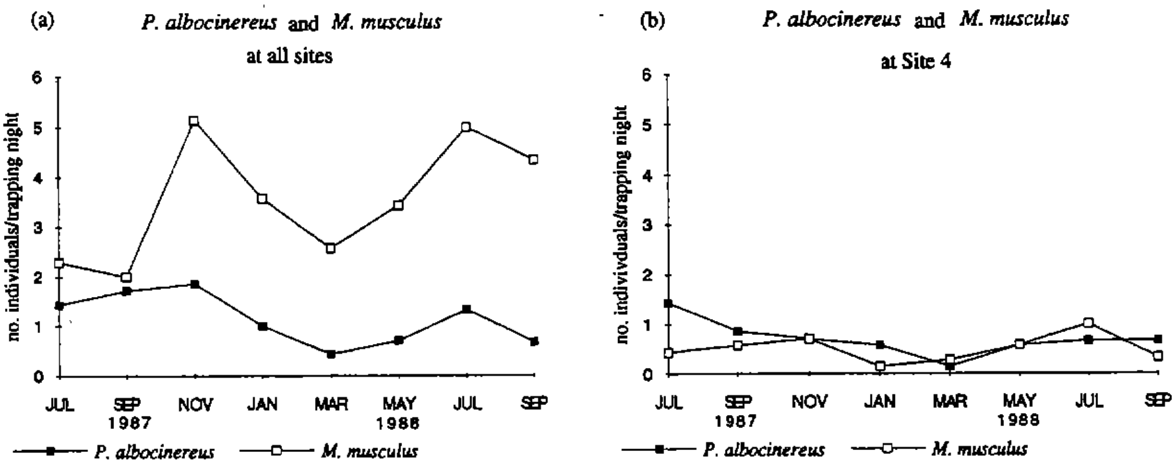

Figure 21: Capture rates for *Pseudomys albocinereus* and *Mus musculus* at (a) all sites and (b) only Site 4

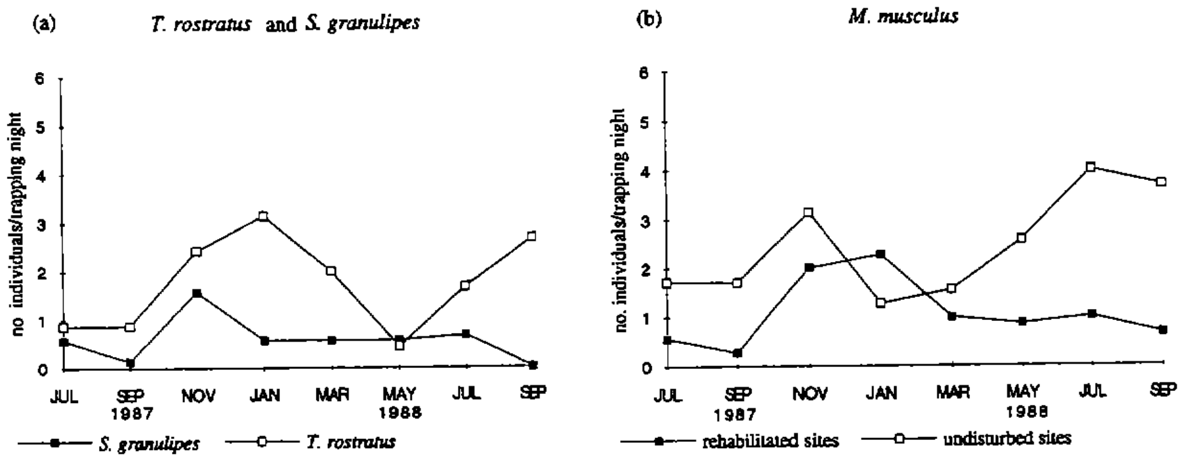

Figure 22: Capture rates for (a) *Tarsipes rostratus* and *Sminthopsis granulipes* at all sites and (b) *Mus musculus* at rehabilitated and undisturbed sites.

albocinereus decreased throughout the study, except at Site 4, where a trough in March was followed by an increase in July and September 1988 (Appendix 3; Figures 20, 21). This trend may be due to animals learning to avoid pitfalls rather than a decrease in population size. The high capture rate at Site 4 in most survey months suggests that the pitfall grid at this location is situated within a *P. albocinereus* colony, and familiarity with the locations of pitfalls is more than offset by the number of animals present.

Peak capture rates for mammals at Sites 1, 2 and 3 occurred at a time of post-breeding, in November, January and/or March, when an increase in numbers and activity was likely to occur. This contrasted with the situation at Sites 4 and 5, which had strong peaks in July, September and November (including the breeding season), followed by troughs in March. *T. rostratus* and *M. musculus* showed the greatest fluctuations in capture rates.

Recaptures were recorded for all mammal species, although they were most common for *P. albocinereus*. All recaptures occurred within sites.

4.3.3 Population structure and breeding activity for reptiles, frogs and mammals

4.3.3.1 *Reptiles*

T. adelaidensis was only trapped at the undisturbed sites SVL's (snout-vent lengths) for this species increased from 25-30 mm in January 1988 to 43-51 mm in September 1988, the latter range being similar to that for animals trapped in September and November 1987 (Figure 23). Murray (1980) identified mature (adult) females with minimum SVL's of 46 mm and mature males with corresponding lengths of 34 mm at similar sites, while Bamford (1992) captured female and male adults with minimum SVL's of 40 and 36 mm, respectively. It therefore appears that only juveniles were trapped in January and March 1988, and a mixture of adults and juveniles in May of the same year, while all individuals trapped in September 1988 and November 1987 were adults. *T. adelaidensis* appears to live for at least two years and can commence breeding at 10 months of age (Bamford 1992).

P. minor trapped in March included four individuals with SVL's less than 60 mm (31-52 mm) and weights that were very low (1-3 g), and which can be considered juveniles. *P. minor* has been observed to hatch at about 30 mm SVL in the wheatbelt (Chapman and Dell 1977). Mature females and males at Badgingarra have been recorded with minimum SVL's of 84 and 67 mm, respectively (Murray 1980). In this study, individuals with SVL's of 92-117 mm, and masses of 16-41g, were recorded. *P. minor* do not breed until they are two years old, and have reached adult size. In coastal areas, *P. minor* tends to reach adult size when SVL's are approximately 85 mm, although equivalent values in the wheatbelt appear to be about 100 mm (Chapman & Dell 1980).

Of eight *C. maculatus* trapped (SVL's 31-56 mm), two captured in March had SVL's of 31 and 35 mm, and could be considered juveniles. No *C. schomburgkii* (SVL's 36-45 mm, n=11) or *C. pantherinus* (SVL's 52 and 70 mm, n=2) were obviously juveniles, although two amongst a total of 13 *C. fallens* (one in January with a SVL of 42 mm and one in March with a SVL of 53 mm) were juveniles or immatures.

D. spinigerus trapped at rehabilitated and undisturbed sites included two juveniles or immatures (i.e., had SVL's less than 56 mm) in September 1987, and one in January 1988 (Figure 24). Only adults were trapped during the remaining survey months.

The legless lizard, snakes and bobtails trapped were all adult in size.

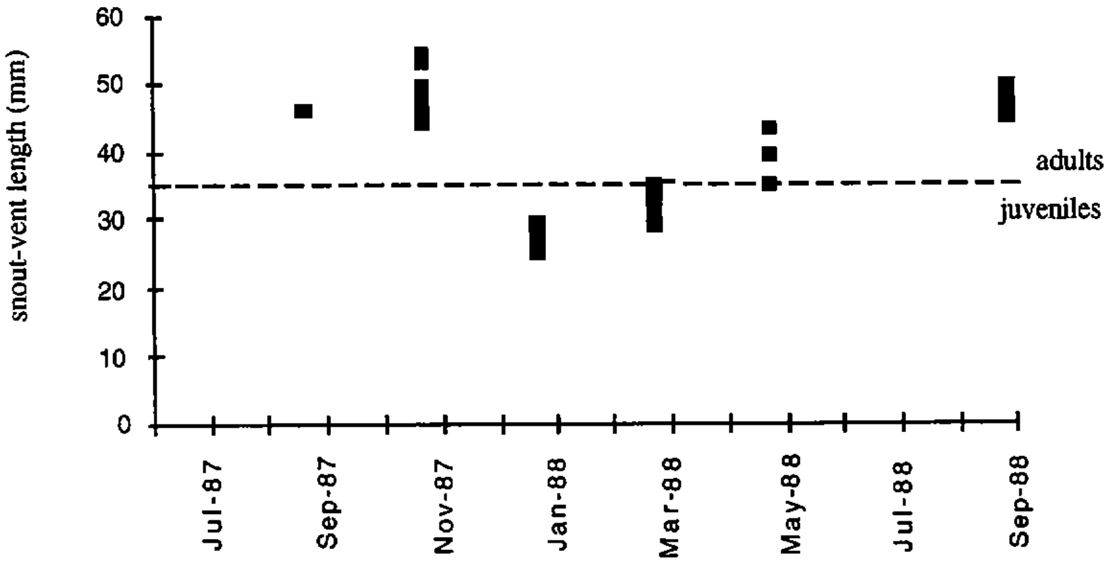

Figure 23: Snout-vent lengths of *Tympanocryptis adelaidensis* trapped at undisturbed sites between September 1987 and September 1988.

4.3.3.2 *Frogs*

Juvenile *P. guentheri* (SVL > 16 mm and < 24 mm) were trapped at undisturbed sites in September and November 1987, and September 1988 (Figure 25). Juvenile *H. eyrei* (SVL > 19 mm and < 31 mm) were trapped at the undisturbed sites in November 1987 and September 1988 (Figure 26). The emergence of juveniles appeared to occur later in 1987 than in 1988. *H. eyrei* metamorphoses at about 17 mm SVL, developing into adults with SVL's of 45-66 mm (Tyler 1976). No young frogs were trapped at the rehabilitated sites.

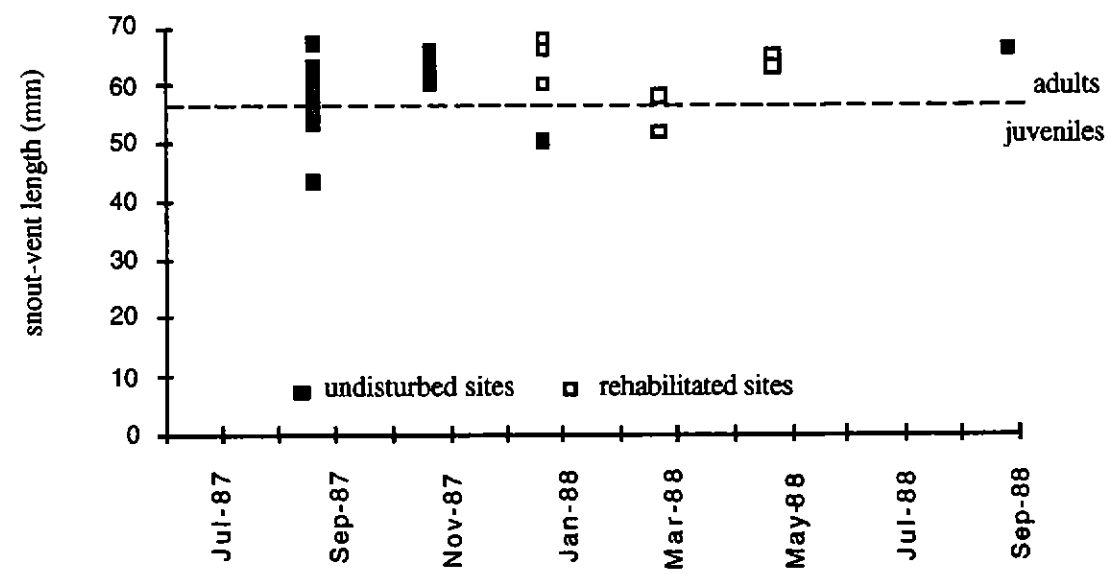

Figure 24: Snout-vent lengths of *Diplodactylus spinigerus* trapped at undisturbed and rehabilitated sites between September 1987 and September 1988.

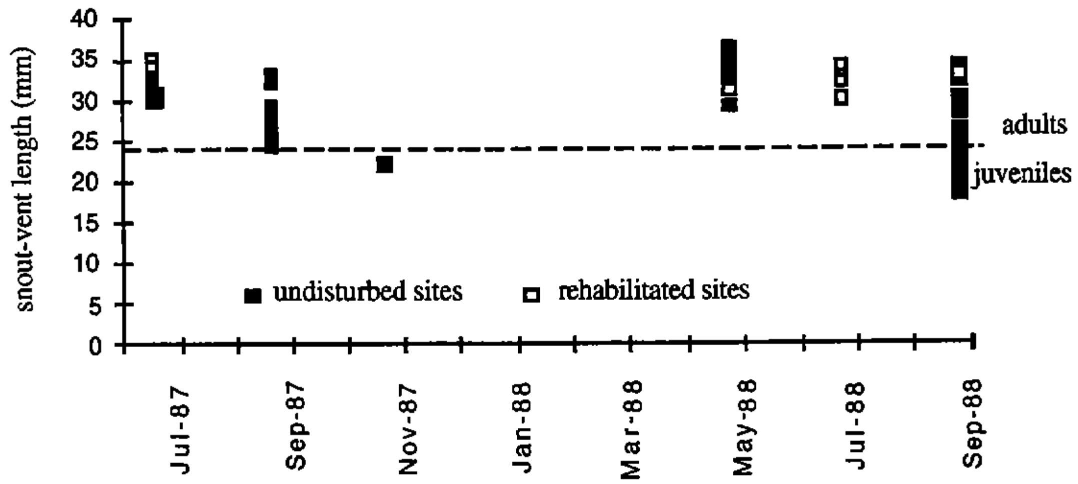

Figure 25: Snout-vent lengths of *Pseudophryne guentheri* trapped at undisturbed sites between July 1987 and September 1988.

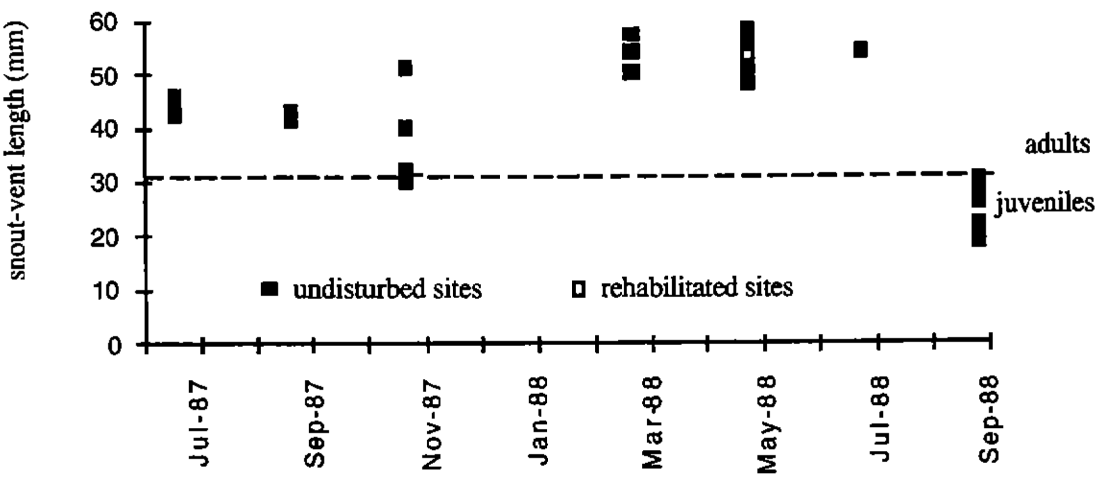

Figure 26: Snout-vent lengths of *Heleioporus eyrei* trapped at undisturbed and rehabilitated sites between July 1987 and September 1988.

Very few juvenile *H. albopunctatus* and *N. pelobatoides* were trapped. One possible juvenile or immature *N. pelobatoides* (SVL = 34 mm) was captured in May 1988, and possibly a few young *H. albopunctatus* (SVL = 46-51 mm) during July and September. *N. pelobatoides* breed during May to July (Tyler *et al.* 1984), with young metamorphosing at about 22 mm SVL, probably in July-August (Tyler 1976). *H. albopunctatus* are expected to metamorphose during September and October, emerging from nest burrows when SVL's are about 19 mm (Tyler 1976). Trapped individuals of *L. dorsalis* and *M. gouldii* were all estimated to be adult.

4.3.3.3 *Mammals*

None of the *S. granulipes* trapped were small enough to be positively identified as juveniles. In November 1987, however, individuals that weighed less than 10 g were captured. Female and male *S. granulipes* trapped in November, January and March had masses in the range of 7.5 to 16.5 g (mostly 7.5-12 g). In contrast, individuals trapped in May, July and September had masses that ranged from 17.0 to 36.0 g (mostly 20-36 g).

Female *S. granulipes* had sizes that varied widely in most months, indicating the presence of individuals from more than one generation, while males showed an increase in body size from November (juveniles completely weaned by this time) to May (when masses were also high), a time when they were likely to begin breeding activity (Figure 27).

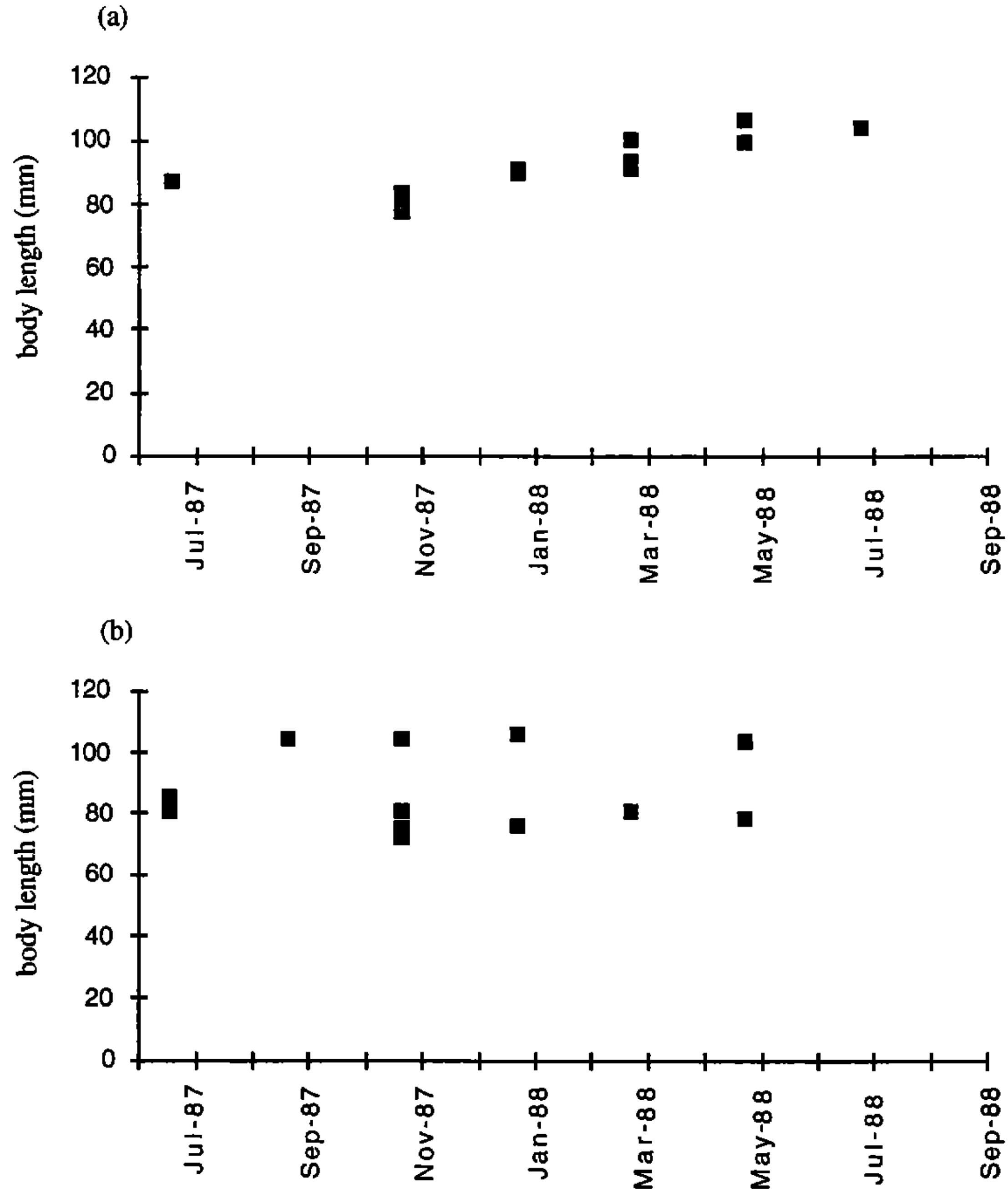

Figure 27: Body-lengths of (a) male and (b) female *Sminthopsis granulipes* trapped at undisturbed sites between July 1987 and September 1988.

Small numbers of young *T. rostratus* (body length < 70 mm in females and < 65 mm in males), and females with young in the pouch, were trapped at the undisturbed sites during each survey month except September 1987 and March 1988 (Figure 28). Two of the females with pouch young were relatively small and did not appear to have reached full adult size, having body lengths of 67 and 63 mm.

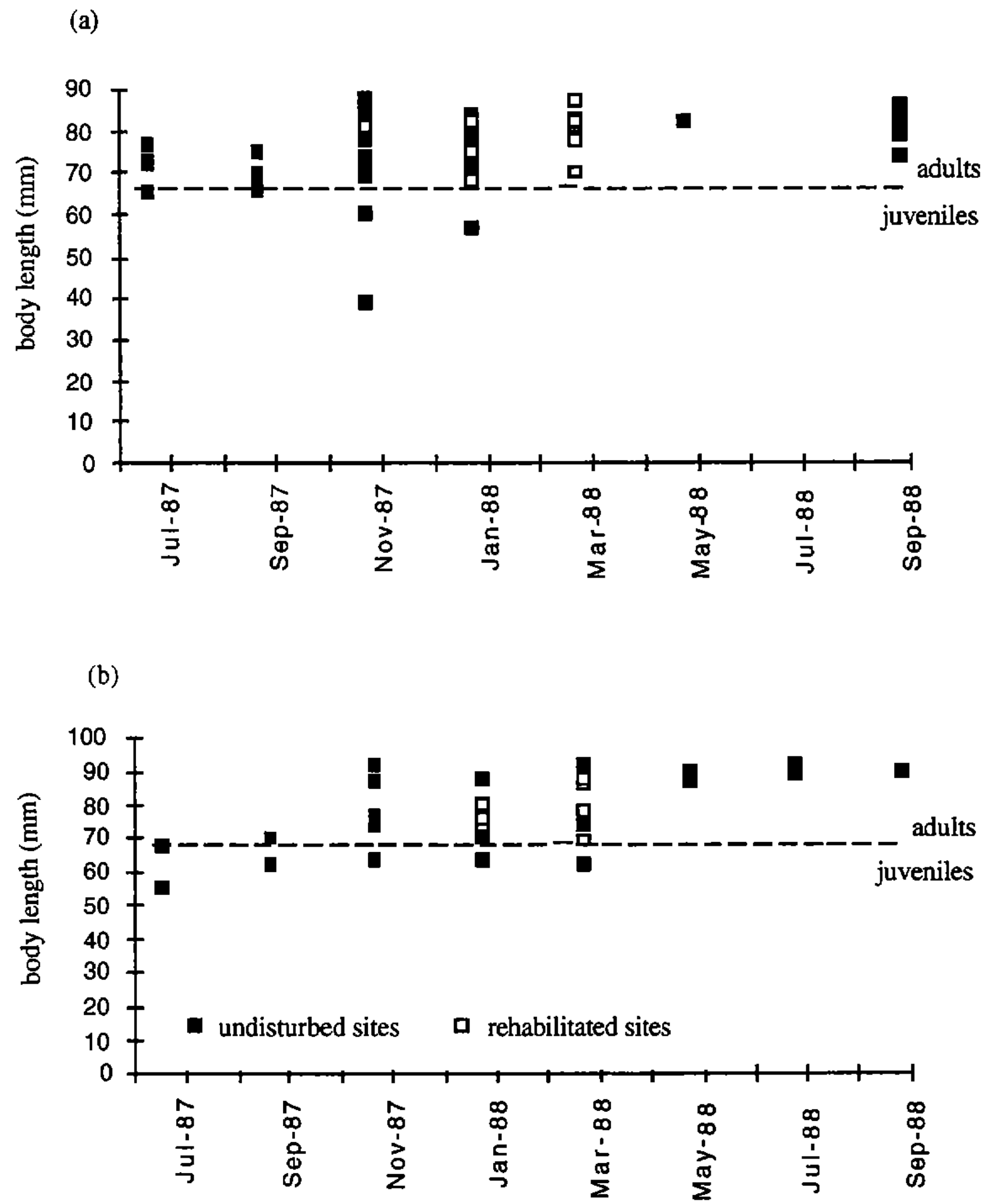

Figure 28: Body-lengths of (a) male and (b) female *Tarsipes rostratus* trapped at undisturbed and rehabilitated sites between July 1987 and September 1988.

Among the *P. albocinereus* captured, females had body lengths and masses that ranged from 59-109 mm and 5-30 g, respectively. Corresponding values for males were 64-116 mm and 11-36 g. Morris (1991) identified adult female and male *P. albocinereus* with body lengths of 63-85 and 63-95 mm, respectively. Only one individual caught during this study had a body length of less than 60 mm, a female trapped at Site 5 in September 1987. She also had a low mass (5 g) for her size (females trapped in July 1987 with body lengths of 64-78 mm had masses of 14.5-16.5 g).

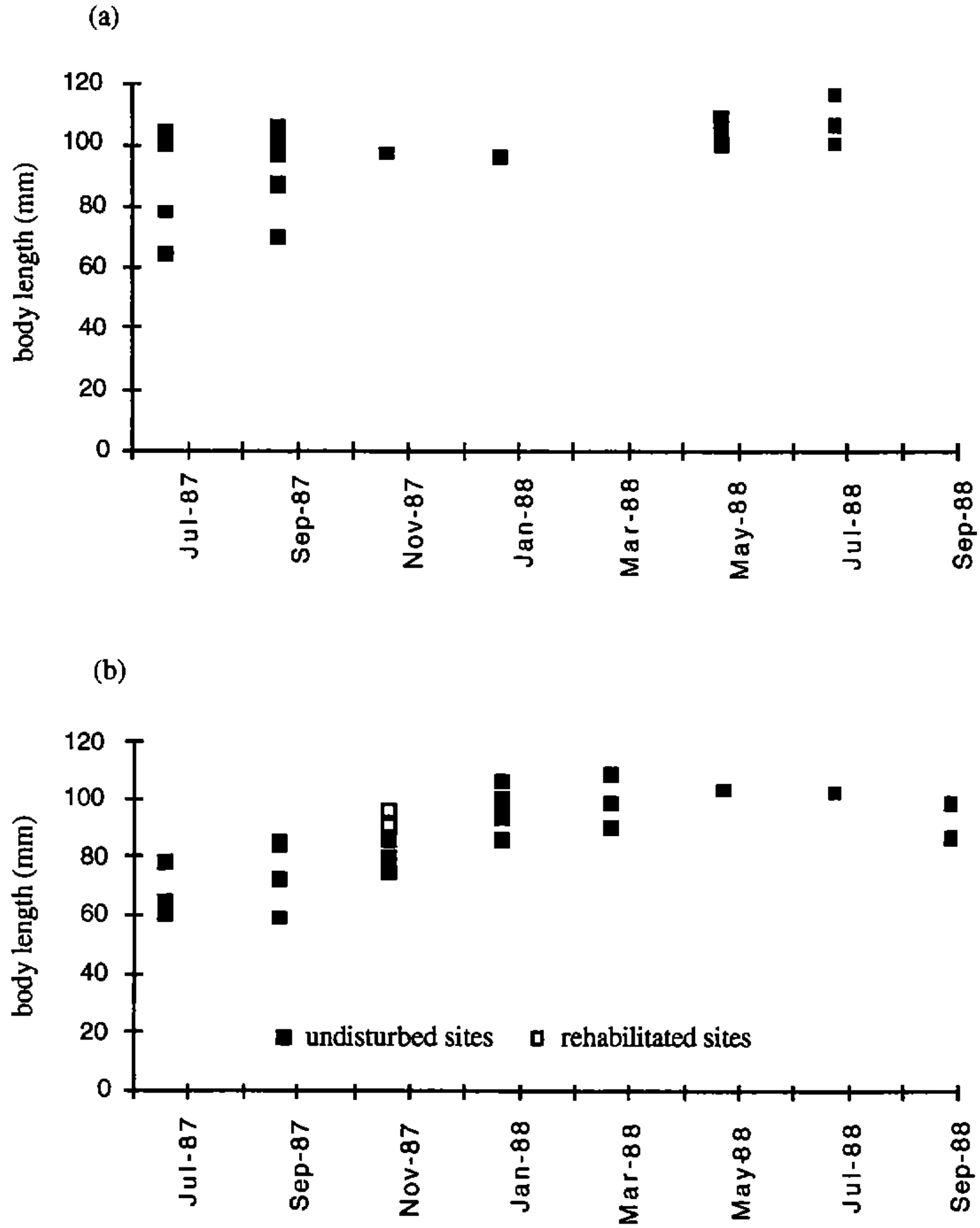

Figure 29: Body-lengths of (a) male and (b) female *Pseudomys albocinereus* trapped at undisturbed and rehabilitated sites between July 1987 and September 1988.

From September 1987 to January 1988, the body lengths of most *P. albocinereus* increased (Figure 29). An increase in mass was also observed, with no individual weighing less than 20 g by July 1988 (Figure 30). Females increased in mass from November to March, and males from May to July. Other studies have shown that males have higher masses than females in July (prior to breeding commencing). For instance, males and females at Marchagee, weighed 31.5-45.5 g and 26-26.5 g, respectively, at this time of year (Chapman & Kitchener 1977). Males are expected to increase in size and mass until August, when breeding commences (Morris & Bradshaw 1981).

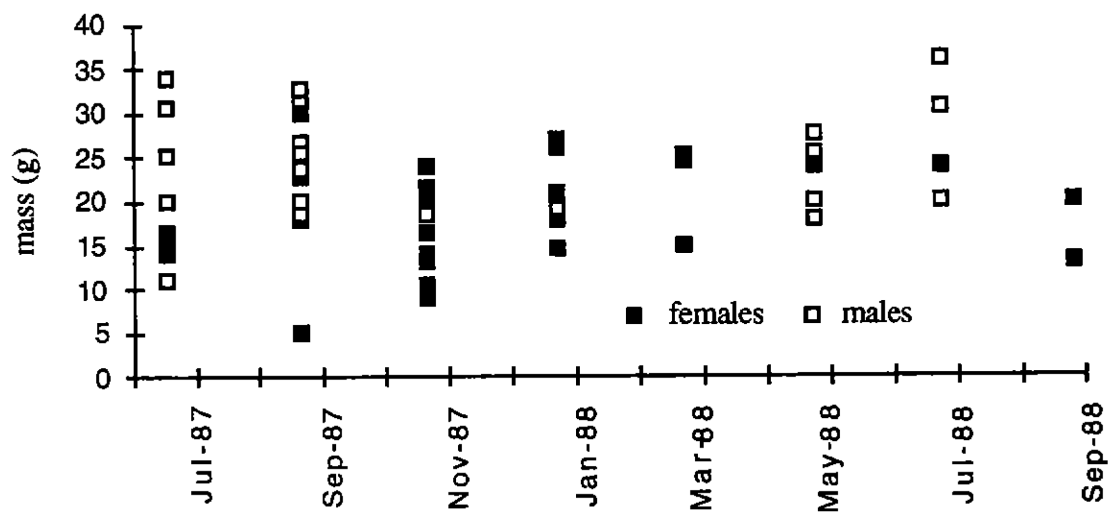

Figure 30: Body masses of (a) male and (b) female *Pseudomys albocinereus* trapped at undisturbed sites between July 1987 and September 1988.

Young *M. musculus* (< 60 mm body length and generally < 10 g) were trapped each survey month except March, May and September 1988 (Figure 31). *M. musculus* tends to be an opportunistic breeder (Newsome 1991), and is able to breed throughout the year. There was a general increase in body length from July to January, values being sustained until July, when juveniles were again trapped. From July 1987 to May 1988, capture rates for females were highest in November and May, whereas rates for males were more consistent between survey months. Capture rates were also high for males and females in July and September 1988.

4.3.4 Bird species presence and relative abundance at each site

The number of different bird species recorded at each site was highest for rehabilitated Site 3 (17 species), followed by Site 1 (15 species) and Site 2 (12 species). However, Site 2 had very few resident, low-heath-cover birds such as fairy-wrens and Calamanthus (Table 8).

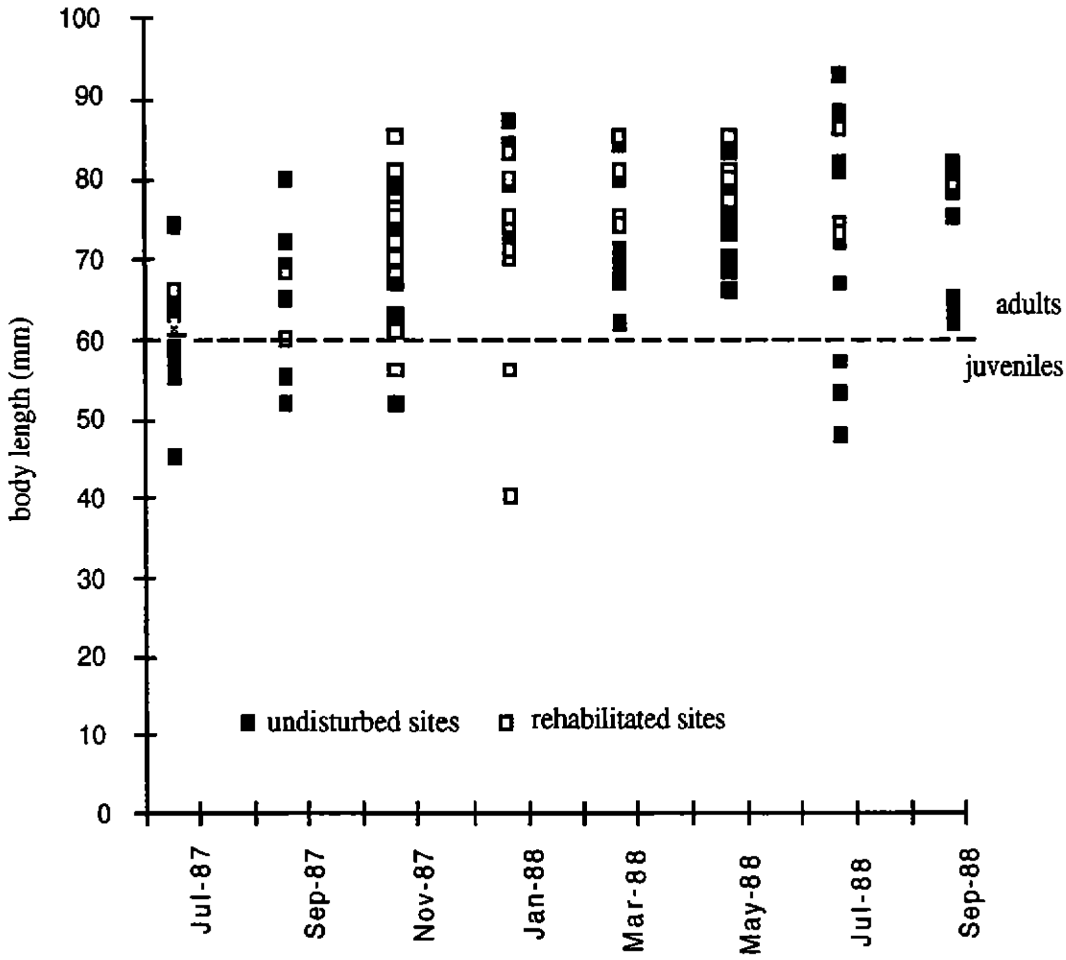

Figure 31: Body lengths of *Mus musculus* trapped at undisturbed and rehabilitated sites between July 1987 and September 1988.

Honeyeaters were the most abundant bird group at the five sites (a maximum of 4.5 to 13 birds/ha). Species included; *Lichmera indistincta* (Brown Honeyeater), *Phylidonyris nigra* (White-cheeked Honeyeater) *Phylidonyris melanops* (Tawny-crowned Honeyeater), *Lichenostomus virescens* (Singing Honeyeater) and *Anthochaera carunculata* (Red Wattlebird). *P. nigra* tended to be the most abundant of these species (Figure 32). Changes in honeyeater numbers were similar at each site, with birds most abundant in May and July. However, Site 3 was unusual in that a second, but smaller, peak in honeyeater numbers was observed in January, a time when the abundance of this group was low at other sites.

Site 3 consistently had the highest number of honeyeaters. *L. indistincta*, *P. nigra* and *P. melanops* occurred at this site during each of the six survey months (although not censused, *L. virescens* was trapped at Site 3 in January and March 1988, and *A. carunculata* was censused in July 1988). At the remaining sites (1, 2, 4 and 5), *L.*

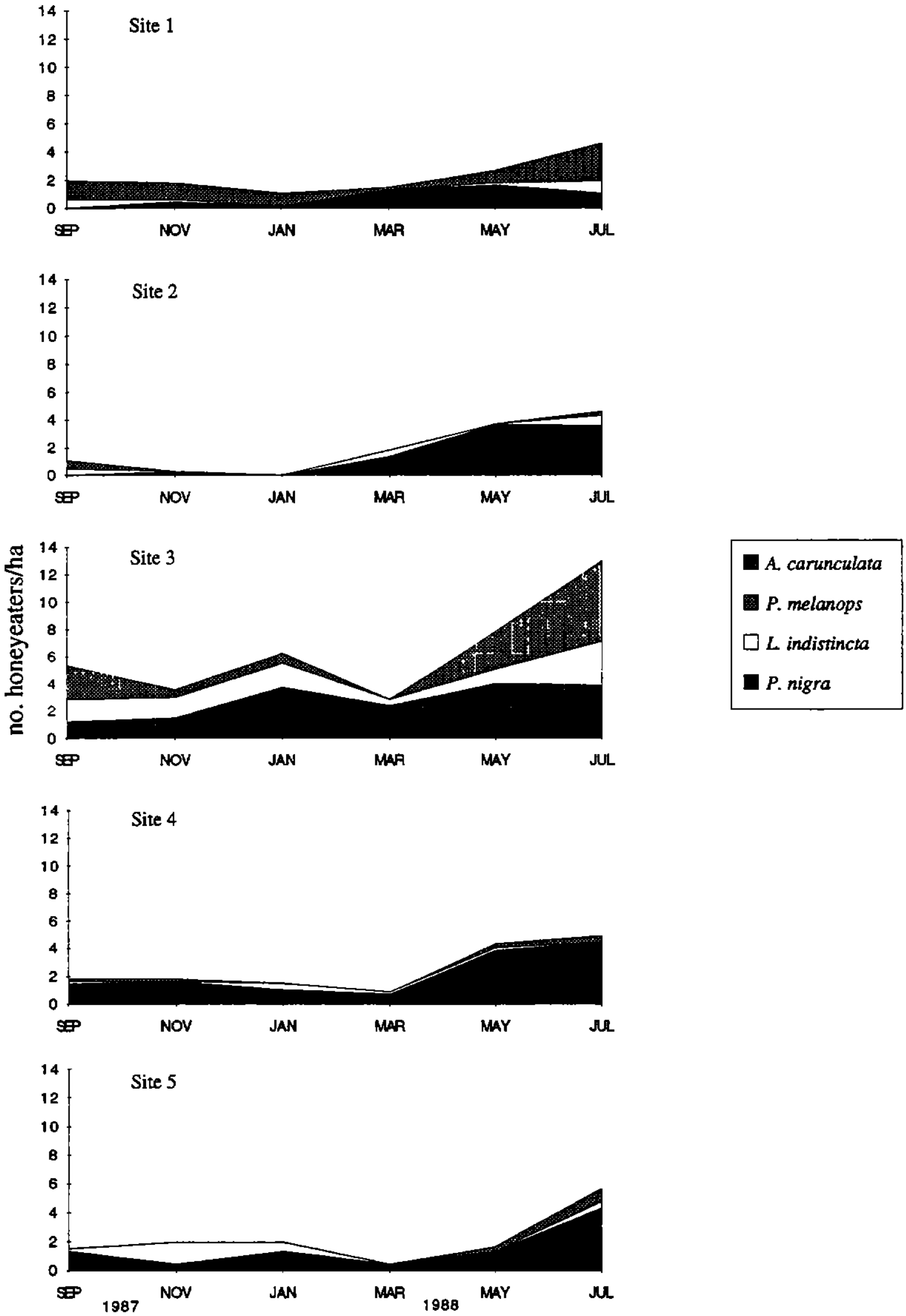

Figure 32: Abundance of honeyeaters during each survey month between July 1987 and May 1988.

indistincta was present during four of the six surveys although in low numbers, and *P. nigra* during each of the six survey months but in greatest numbers at Sites 4 and 5. *P. melanops* was most abundant at Site 1 (throughout the six survey months) and present in low numbers at Sites 2, 4 and 5 (during the winter and spring months). No honeyeaters were censused in January at Site 2.

No evidence of movements by honeyeaters between sites was recorded, as the four recaptured honeyeaters were all recaught within sites. Of the two *L. indistincta* recaptured, one was trapped between surveys at Site 3 (July 1987 to September 1987) and the other was trapped within a survey at Site 3. Of the two *P. nigra* recaptured, one was recaptured between surveys at Site 1 (September 1987 to May 1988) and the other within a survey at Site 5.

The density of birds other than honeyeaters was generally low (less than 3 birds/ha for each site), although these birds were slightly more abundant during the May, July and September surveys than at other times (Figure 33). These fluctuations were due to high numbers of *Cheramoeca leucosternum* (White-backed Swallow) recorded at Site 5, *Cacatua roseicapilla* (Galah) and *Malurus lamberti* (Variegated Fairy-wren) at Site 4, and *Malurus leucopterus* (White-winged Fairy-wren) at Sites 1, 2 and 3. *C. roseicapilla*, *Corvus coronoides* (Raven), *Artamus cinereus* (Black-faced Woodswallow), *C. leucosternum* and *Rhipidura leucophrys* (Willie Wagtail) were also present in significant numbers at Sites 2 and 3.

M. leucopterus was recorded as the most abundant fairy-wren and observed at all sites except Site 5 (Table 8). This species contrasted with *Malurus splendens* (Splendid Fairy-wren), which was only recorded at Site 1, and *M. lamberti*, seen only at undisturbed sites. *Rhipidura fuliginosa* (Grey Fantail), *Calyptorhynchus baudinii* (White-tailed Black Cockatoo), *A. cinereus* and *Chrysococcyx basalis* (Horsfield's Bronze-Cuckoo) were only censused or recorded at Site 3. *Petroica goodenovii* (Red-capped Robin) was only recorded at Site 5 and *Ocyphaps lophotes* (Crested Pigeon) at Site 1.

4.3.5 Evidence of breeding activity by honeyeaters

There was evidence of breeding activity by *P. melanops*, with the capture of juvenile birds in November 1987 at Sites 1, 2, 3 and 5, in January 1988 at Site 1 and in March 1988 at Site 3. Breeding is likely to have occurred during the spring and early summer months. One honeyeater nest with one chick (probably of *P. melanops*) was located at Site 1 during September in a *Conospermum triplinervium* (Smoke Bush). Unidentified old

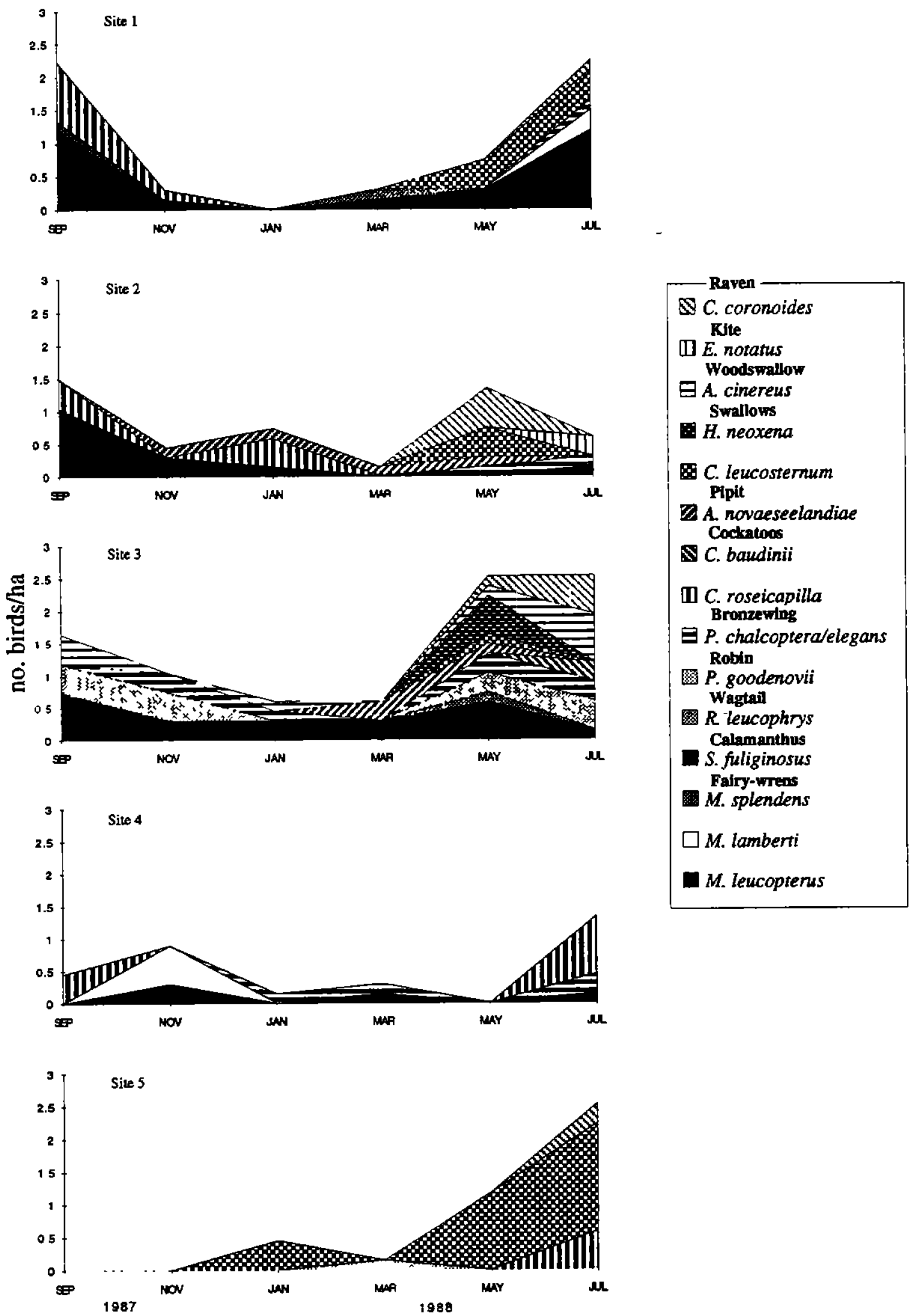

Figure 33: Capture rates for birds other than honeyeaters during each survey month between July 1987 and September 1988

honeyeater nests were located in a *Banksia leptophylla* bush at Site 1 and *Adenanthos cygnorum* bushes at Site 3.

Although juvenile *P. nigra* were not identified during this study, there is strong indirect evidence that the species was nesting in the area. Male birds, as determined from total head measurements (Rooke 1976), and which had short wing lengths (71-72 mm), were trapped in September (four birds) and November (two birds) at Site 3. Female birds with short wing lengths (65-66 mm) were trapped in July (one bird) at Site 3 and November (two birds) at Sites 3 and 5 (Appendix 4). These birds were considered likely to be juveniles (Congreve 1992).

4.4 Discussion

The incidence and abundance of vertebrates at the five sites studied are considered below in relation to the biology of each species and characteristics of the sites.

4.4.1 Reptiles

Many reptiles burrow into the soil at various times of the year. Skinks, with the exception of *Tiliqua rugosa*, use the soil for shelter. *Ctenotus fallens* has been observed as deep as 10 cm into the soil (Bamford, pers. comm.). Dragon species dig into the ground to lay their eggs Among the snake species trapped during this study, *Vermicella littoralis* (West Coast Banded Snake) also burrows into the soil. The ability of reptiles to use the soil in these ways is to a large extent determined by characteristics of the soil such as moisture content, hardness and composition. Evidence obtained in other investigations has indicated that the soil in rehabilitated regions is significantly different from that at undisturbed sites, being harder and having an inferior drainage capacity (Marshall 1983). These differences are likely to be major reasons why few reptiles were trapped at the rehabilitated sites during this study.

A secondary factor that may explain the low incidence of skink and dragon species at rehabilitated sites is the occurrence of large patches of bare ground (at Site 3) and low shrub cover (at Site 2). Low shrubs and leaf litter provide shelter from predators and extreme weather conditions (Nichols & Bamford 1985), in addition to providing important foraging areas. Leaf litter is especially important for *Ctenotus schomburgkii*, *C. fallens*, *Ctenotus pantherinus*, *Lerista praepedita* and *Lialis burtonis*. Species such as *T. rugosa* rely on logs, rocks and other objects, as well as vegetation, for shelter. In contrast, the most abundant reptile trapped at the rehabilitated sites (*Diplodactylus spinigerus*) is semi-arboreal and therefore less affected by ground litter and areas of bare ground. Kikkawa *et al.* (1979) and Burke (1980) have shown that soil type and characteristics of the leaf litter are generally more important than canopy cover in determining the presence of different species of reptile.

Habitat preferences may help to explain the apparent absence or low occurrence of some skinks and dragons at particular sites (Nichols & Bamford 1985). The greater the number of vegetation associations which occur in an area, and the diversity of substrates supporting these associations, the greater the number of reptile species present (Storr 1964; Kitchener *et al.* 1980). Each of the undisturbed sites in this study had soil-type, landform and drainage characteristics that supported different vegetation associations.

C. schomburgkii was only trapped at undisturbed sites that had the highest ground cover, i.e., at Sites 4 and 5. Studies in the wheatbelt of Western Australia suggest that this species may prefer areas with significant amounts of ground cover (Chapman & Dell 1979). Among the dragon species, *Pogonus minor* was trapped at all but one (rehabilitated) site, an occurrence that may reflect this species' ability to live in a wide variety of habitats (Cogger 1979). Specific habitat preferences by the three dragon species may be indicated by the higher capture rates of *P. minor* at Site 1, *Ctenophorus maculatus* (a terrestrial dragon) at Site 5 and *Tympanocryptis adelaidensis* (a small terrestrial dragon) at Site 4. Both *C. maculatus* and *T. adelaidensis* have been described as having a preference for sandy soils (Cogger 1979).

D. spinigerus was trapped in high numbers during the spring months (September and November) of 1987, a time when the females would have been gravid and most active. Large numbers of *D. spinigerus* were not trapped in the spring (September) of the following year, possibly indicating that breeding activity was delayed during 1988. The drop in capture rates for this species in January and March may have been due to animals being less active on the ground, due to high soil-surface temperatures during the day, remaining instead within the canopy of the vegetation. This behaviour contrasted with that of two skink species, *C. schomburgkii* and *C. fallens*, and the three dragon species, where capture rates remained high during these months. Many members of the genus *Ctenotus* are known to be active at very high temperatures (Cogger 1979).

Evidence of breeding activity was obtained for several species, young being detected during the summer months. Reptiles are seasonal breeders in this environment, reproducing each spring. Females become gravid in October (Chapman & Dell 1978), although in some instances gravid animals have been observed as early as August and September (Murray 1980). Monthly trapping surveys would greatly increase the number of juveniles trapped during this time and give more data on breeding activity and reproductive success. Although not distinguished in this study, the sex of species such as *T. adelaidensis* can be determined on the basis of coloration features (Bamford 1992).

4.4.2 Frogs

The capture of a particular species of frog does not necessarily indicate that a given site is suitable for that species. Frogs generally have the ability to travel considerable distances over large areas of bare ground or grassland when moving to their breeding grounds. An exception is *Myobatrachus gouldii*, which appears to be able to breed independently from surface water (Watson & Saunders 1959). All frog species trapped during this study burrow. Evidence of the suitability of rehabilitated or undisturbed sites for these frogs species would presumably be obtained if frogs were located in burrows or observing burrowing.

The higher capture rate of frogs at Sites 4 and 5, compared to other sites, can be explained by their proximity to wetlands. Site 4 is situated near the rise of a hill, 380m south of Site 5 which occurs on lower land and is part of a small wetland (identified as Site 13 by Elkington (1986)). At least five other small wetlands occur within 500 - 900m north-west to east-north-east of Site 5. These wetlands provide surface water that is needed during the winter months if frogs are to breed. Some of these wetlands are likely to vary with regard to the time for which they hold water, as they differ in size, depth and relationship to the water table (Elkington 1986).

Higher capture rates of frogs in July and September 1988 are real, although exaggerated somewhat due to the use of large pitfalls in 1988. Differences can be attributed to the higher rainfall experienced during 1988. Total rainfall in April and May 1988 was 149 mm compared with 84 mm in the corresponding months of 1987 (Figure 1).

Both *Neobatrachus pelobatoides* and *Heleioporus eyrei* were trapped during their breeding seasons. *N. pelobatoides* was captured in May and July, and *H. eyrei* during May (when they are expected to move to their breeding grounds), and September (when they are expected to move away from their breeding grounds). *N. pelobatoides* lays its eggs on the surface of temporary bodies of water, usually above clay substrates (Main 1965), and burrow in clay and loam soils away from water during the non-breeding season (Tyler *et al.* 1984). *H. eyrei* requires water bodies that flood for at least two to three months of the year, and its eggs are laid within burrows in sandy soils or swampy areas during autumn (Lee 1967). During the dry months, it aestivates in burrows away from water.

Limnodynastes dorsalis tends to live in burrows not far from water, a fact that may explain the low numbers trapped during this study. Eggs are laid in winter or spring in a frothy mass on the surface of water (Main 1965). *Heleioporus albopunctatus* aestivates deep in the sand, where conditions are still moist during the months when rainfall is low. Eggs are laid in a burrow on the banks or bed of shallow water bodies (Lee 1967). The large numbers of this species trapped in May would coincide with their breeding season. *Pseudophryne guentheri* lays its eggs within a burrow following late summer or early winter rains. Hatching does not occur until the burrow floods. Adults occur in damp habitats on the ground, under logs, rocks or dead grass (Main 1965). The capture of large number of young frogs at Site 5 in September coincided with the time of metamorphosis, and may indicate that this species breeds within the wetland that is part of this site.

M. gouldii was trapped at the undisturbed Sites 1 and 5. This species typically occurs on sandy soils in dense scrub and heath (Cogger 1979; Tyler *et al.* 1984). All three of the undisturbed sites at Eneabba would fit this general description. Individuals are known to feed on ants and termites (Calaby 1956; Murray 1980), but may have a broader diet than has been documented so far (Bamford, pers. comm.). *M. gouldii* lays its eggs in summer or early autumn (Watson & Saunders 1959; Davidge 1980; Murray 1980). Higher numbers of this species could presumably be trapped by opening pitfalls after the occurrence of summer rains, which initiate breeding activity.

4.4.3 Mammals

Mammals vary in their ability to colonise new areas, with species that can rapidly increase their population size and are reasonably mobile tending to be initially most successful. The availability of appropriate food and shelter is also an important determinant of which species are capable of colonising these areas. Within heathlands, the density of plant cover is thought be an especially critical factor in determining the distribution and behaviour of mammals (Kikkawa *et al.* 1979). Small mammals are able to form runways through dense heath, thus obtaining protection from predators and extreme weather conditions during the day and night.

Pseudomys albocinereus is a nocturnal rodent with the capacity to recolonise areas relatively quickly, providing adequate food and shelter are available. This species has been recorded recolonising areas 3-6 years after fire (Bamford 1986). Females produce 2-6 young per litter (Chapman & Kitchener 1977), and young born in August have been found, in some years, to breed three months later in November (Bamford 1986).

A closely-related species, *Pseudomys novaehollandiae*, is known to have re-appeared 4-5 years after the top soil had been replaced at rehabilitated sites in New South Wales, and peaked in numbers after 8-9 years (Fox & Fox 1984). Only two individuals of *P. albocinereus*, however, were trapped at the rehabilitated Eneabba Sites 2 (five years old in 1987) and 3 (ten years old). In both cases, it was an adult female trapped in November. These captures coincided with the existence of peak numbers at undisturbed sites, and occurred at a time when young born in the spring would have been fully weaned, and adult females more mobile. It may also be significant that the vegetation at Site 3 included an open tall shrub component, whereas that at Site 2 included very open low shrubs (Dell & Chapman 1981; Morris & Bradshaw 1981).

During the day, *P. albocinereus* live in burrows that can be 60 cm deep and extend for 3-4m, usually located in sandy soils with some gravel content (Morris 1991). The high capture rates of *P. albocinereus* at Site 4 during each survey month, suggest that a colony was established at this site. The relatively low capture rates of *Mus musculus* (House Mouse) at the same site may have been due to limited burrow space and the high numbers of *P. albocinereus*. Studies of interactions between *P. novaehollandiae* and *M. musculus* in New South Wales have indicated that *P. novaehollandiae* in large numbers can displace *M. musculus* (Fox & Pople 1984), although in situations where *M. musculus* has been able to achieve high population densities, *P. albocinereus* numbers decrease (Fox & Gullick 1989).

The success of *M. musculus* in the Australian environment appears to be partly due to its ability to utilise environments where vegetation has been recently-burnt or the soil has been disturbed in some way. The nomadic nature of *M. musculus* also enables it to move easily into or out of areas according to need or opportunity. Although *M. musculus* tends to occupy a greater diversity of habitat than native mammals, it seems to be most abundant in coastal heaths and shrublands (Chapman 1981).

High capture rates for *M. musculus* at Eneabba's Site 5 may have been due to the presence of surface water, especially in 1988, as within generally dry undisturbed environments, *M. musculus* is often more abundant under these conditions (Bamford, pers. comm.). Rainfall and surface water are also likely to influence the abundance of *M. musculus* by making the soil more suitable for burrowing and generating an increased food supply (Chapman 1981; Newsome 1991). Within rehabilitated areas, *M. musculus* shows a preference for soil that is friable, supports dense vegetation and has relatively few exposed areas of bare sand (Fox & Fox 1984). At Eneabba, the high autumn rainfall in 1988 may have increased the abundance or activity of *M. musculus* during May to July at the undisturbed sites, and decreased their abundance at the rehabilitated sites due to surface water and the water logging of soils. Peak capture rates at the rehabilitated sites in November and January may have been a response to increased food availability at these sites.

Sminthopsis granulipes is a carnivorous marsupial that tends to be associated with sandy soils, in sparse to mid-density shrubland that is usually less than one metre high (Kitchener 1991). Site 1 recorded the highest capture rates for *S. granulipes*, and had vegetation of this type. The remaining two undisturbed locations, Sites 4 and 5, supported taller heaths with higher densities of plants and/or canopy cover.

Sminthopsis species are usually slow to colonise disturbed or rehabilitated areas. For instance, *Sminthopsis murina* has been observed entering post-mining succession approximately eight years after regeneration has commenced (Twigg *et al.* 1989). It is therefore not surprising that *S. granulipes* was not trapped at the rehabilitated Eneabba sites. Sedentary behaviour (movements of only up to 500m have been recorded), and relatively low reproductive rates (one litter a year), would greatly reduce this species' ability to colonise new areas.

Populations of *S. granulipes* at Eneabba appeared to be very stable from year to year, with low numbers present each September (when males die), peaks in November (when juveniles are fully weaned) and a plateau in abundance during the remaining months. These observations are supported by the results of other studies, where there has been evidence that young are born in winter and possibly weaned by late September to October (Kitchener & Chapman 1978). Female *S. granulipes* live for several years, hence the large range in the sizes of animals trapped during most survey months.

Tarsipes rostratus, a predominantly nocturnal marsupial with a diet of nectar and pollen, can move distances of several km overnight (Collins *et al* 1988, Wooller *et al.* 1993). It occurs in undisturbed habitats where a range of plant species maintain a continuous supply of food throughout the year. The mobility of this species would have enabled it to use rehabilitated Sites 2 and 3 in November, January and March, even though appropriate food may not have been available year-round at these locations (see Chapter 5).

T. rostratus has the ability to breed throughout the year, providing there is a good supply of food, although breeding activity is usually lowest between January and March (Scarlett & Woolley 1980; Wooller *et al.* 1981). Females with young are more sedentary than other animals, and therefore reliant on a good localised supply of nectar (Wooller *et al.* 1981). This observation may provide an explanation for the fact that no females with pouch young were trapped at the rehabilitated sites.

Rehabilitated sites should provide *T. rostratus* with fewer barriers to colonisation than they would for *S. granulipes* or *P. albocinereus,* since the former shelters above ground, and is more opportunistic in its breeding and feeding behaviour. The higher clay content and hardness of soil at rehabilitated sites would not pose the same problems as they would for burrowing mammals.

T. rostratus trapped at Eneabba had lower masses, although similar body lengths, than those trapped in other studies near the south coast of Western Australia. At Eneabba, mean weights were 8g for females and 6g for males, compared with corresponding values of 11g and 9g, respectively, at more southern sites such as the Fitzgerald River National Park (Wooller *et al.* 1981; Kitchener 1991). Other studies at Cooljaloo and Mooliabeene have also indicated that northerly populations of *T. rostratus* have smaller body masses than those on the south coast (Bamford, pers. comm.).

4.4.4 Birds

Phylidonyris nigra (White-cheeked Honeyeater) and *Lichmera indistincta* (Brown Honeyeater) can be opportunistic and mobile in their behaviour, moving into areas when nectar resources are suitably abundant (Keast 1968). Although *Phylidonyris melanops* (Tawny-crowned Honeyeater) is often considered resident or sedentary within an area (Keast 1968; Serventy & Whittell 1976), it can show seasonal changes in abundance such as those observed at Eneabba (Wooller 1981). During this study, the abundance of all three species peaked during May and July, while numbers were lowest in January and March. These trends can be related to flower abundance (see Chapter 5) and breeding activity.

Mobile populations of honeyeaters tend to be made up of resident and transient birds, with resident birds generally nesting during winter and spring (Paton 1985). At sites near Beverley, Western Australia, juvenile *P. nigra* have been trapped from July to December, with the first pullus (nestling) captured in May and the last as late as early November (P. Congreve, unpub. data). Studies near Pingelly have found *P. melanops* to be breeding in August and September (Halse 1978). In this study, nesting activity by *P. nigra* may not have started until July or August, and by *P. melanops* not until September. When nesting has finished, honeyeaters often move out of an area, although small numbers of birds often remain. In this study, the relatively strong flowering at Site 3 during the summer months may have enabled a larger number of *P. nigra* and *L. indistincta* to persist in the area than would normally occur.

P. melanops is closely associated with heathland habitats (Blakers *et al.* 1984). This species' dominance and persistence at Sites 1 and 3, where there is a high diversity of nectar-producing plants, reflects its specialisation towards low heaths with a high plant diversity rather than dense, taller, less diverse heaths such as those at Sites 4 and 5.

The large numbers of honeyeaters censused and trapped at Site 3 can be attributed to the frequency of flowers per plant, with plant size more than compensating for low plant density. The occurrence of *Lichenostomus virescens* and the large *Anthochaera carunculata* at Site 3 could be a consequence of the considerable nectar resource available, and perhaps the presence of a tree stratum that is usually absent or very sparse within heathlands. Wilson (1974) and Kitchener *et al.* (1982) have observed that the addition of trees greatly increases bird species diversity.

Bird species other than honeyeaters can provide useful information regarding the habitat provided by a particular vegetation structure or association. In particular, various *Malurus* species (fairy-wrens) tend to utilise different types of heaths. This was evident in that the three species of *Malurus* observed during the present study differed in their distribution and abundance among the five sites.

4.4.5 Conclusions and recommendations

With the exception of honeyeaters, only a few species of animal were supported at rehabilitated Sites 2 and 3. Species that appear to have established residential populations included *Diplodactylus spinigerus* and *Mus musculus*. There was no evidence that populations of skinks or dragons were resident or breeding at rehabilitated sites. The main factor likely to have limited recolonisation by animals is the nature of the soil. Many of the reptile species require sandy soil, with varying amounts of lateritic gravel or clay, if they are to burrow successfully. Two mammal species, *Pseudomys albocinereus* and *Sminthopsis granulipes*, and the frog *Myobatrachus gouldii*, are also closely associated with sandy soils. *Tarsipes rostratus*, although not directly affected by the nature of the soil, is indirectly dependent on sandy soils because the latter support plants that provide a year-round supply of pollen and nectar.

Because of their dependence on soil characteristics, reptiles may be one of the most useful indicators of the success of habitat rehabilitation. Native mammals are also an important indicator group, although they suffer from the disadvantage that they are unlikely to colonise rehabilitated areas until several years after regeneration has commenced. Frog species are very mobile, and therefore not such good indicators. An exception is *M. gouldii*, which is specially adapted to sandy heathland soils, and although possibly nomadic in its movements (Bamford 1986), does not appear to have seasonal movements to breeding sites. Honeyeaters are good indicators of nectar availability and vegetation structure, as their abundance and nesting activity responds rapidly to variations in these factors. More sedentary birds such as fairy-wrens and robins are also good indicators of habitat suitability, although often rare within relatively small sites such as those used in this study.

It would be of great benefit if the number of reptiles and frogs trapped per survey could be increased beyond levels achieved in this study. Changes in population structure and size, breeding activity and movements between sites would then be more easily determined. Captures, especially for dragons and frogs, could be increased by using 40-50 larger-sized pitfalls (28 cm diameter and 40 cm deep), rather than the small pitfalls employed in this study. The number of reptiles, frogs and mammals trapped could also be enhanced by increasing sampling intensity, either by undertaking monthly surveys or increasing the number of trapping nights per survey. The use of more Elliotts might also increase the numbers of *Tiliqua rugosa*, *Ctenotus fallens* and *M. musculus* caught. The use of drift-line fences near pitfalls might increase capture rates (Williams & Braun 1983; Friend 1984; Read 1985; Cockburn *et al.* 1987; Morton *et al.* 1987), although the results of this study suggest that they may not be equally effective for all vertebrate groups.

5. Food Sources And Their Use By Vertebrates

5.1 Introduction

Australian heathlands such as those at Eneabba support a wide range of plant species (Hopkins & Hnatiuk 1981, Hopkins *et al.* 1983; Lamont *et al.* 1984), although fauna are much less diverse (Kikkawa *et al.* 1979). Low animal species diversity is at least partly due to the low productivity of these heathlands, which is a consequence of the nutrient-poor, sandy soils on which the plants grow (Kikkawa *et al.* 1979; Bettenay 1984), the short growing season and low rainfall (Beard 1976).

The main sources of food for animals that inhabit heathlands appear to be leaf litter and flowers (Kikkawa *et al.* 1979). Most of these animals forage opportunistically, and only a few species appear to have specialised diets (Kikkawa *et al.* 1979). Animals such as arthropods and reptiles not only obtain nourishment from leaf litter, but also contribute to nutrient recycling within each ecosystem. Some arthropods, honeyeaters and small mammals such as *Tarsipes rostratus* are dependent on the all-year-round supply of nectar produced by flowers for their survival (Collins & Briffa 1982; Paton 1982; Wooller *et al.* 1983a; Collins *et al.* 1988; Nichols *et al.* 1989; Collins *et al.* 1990). It is also likely that insectivores are reliant to some extent on arthropods supported by flowers that they visit.

This chapter identifies plant species that are used as sources of food by different vertebrates, particularly honeyeaters and mammals. The occurrence and abundance of these animals at each of the five sites is also compared with the abundance and flowering phenologies of relevant plant species. The use of food items by reptiles and frogs at Eneabba is inferred principally from data available in the literature.

5.2 Methods

5.2.1 Indirect evidence of food utilisation by vertebrates

Pollen smears were taken from the heads of trapped mammals and birds using small cubes of basic fuchsin gel, and grains counted using a light microscope at 400x magnification (Wooller *et al.* 1983b; Collins *et al.* 1990). Where the number of pollen grains per slide was relatively low, i.e., less than 100, all grains were counted. In other cases, grains were counted in five randomly-selected fields of view.

Pollen grains were generally identified to species by comparison with type specimens, although difficulty was experienced in distinguishing between some species that flowered concurrently. The species of greatest concern were *Banksia leptophylla* and *Banksia grossa* in March, May and July, *Eucalyptus tetragona* and *Eucalyptus todtiana* in January, and *Calothamnus quadrifidus* and *Calothamnus villosus* in September. In situations where only one of each pair of species occurred at a site, it was assumed that pollen from this species was being carried.

Faecal samples were also collected and examined microscopically to ascertain whether pollen and insects had been eaten. Pollen was again identified to species level where possible, although only the presence or absence of insect remains was recorded.

5.2.2 Direct evidence of food utilisation by vertebrates

Opportunistic observations of foraging by birds were made at each site, with particular attention paid to the main food plants and substrates used by these birds. Foraging activities included hawking, aerial feeding, ground feeding and the probing of flowers. Estimates of the relative importance of different nectar-producing flowers to honeyeaters was made by following individual birds for as long as possible and recording the times spent probing different types of flowers. These data were combined with information obtained from the examination of pollen smears to gauge the importance of different plant species at each site and at different times of the year.

5.2.3 Influence of food availability on the abundance of vertebrates

Floral abundance for the major plant species used as a source of food by *Tarsipes rostratus* and honeyeaters was estimated from flower (or inflorescence in the case of *Banksia* and *Dryandra*) counts and plant density estimates made at each site (see Chapter 3). Values were expressed as the mean number of flowers/plant x no. of plants/0.56 ha, or alternatively as the mean number of flowers/plant x number of plants used in the flower counts/site (when the number of plants was less than 30). Flower counts were conducted from June 1987 to May 1988, although bird censuses were undertaken from September 1987 to July 1988.

Previous studies have shown that peak nectar production by large *Banksia* inflorescences tends to be 150 times that of single *Grevillea* flowers, and 3-4 times that of *Dryandra* and small *Banksia* inflorescences (Collins & Newland 1986; Collins *et al.* 1990). Rough estimates of relative floral abundance (and therefore energy production) by *Banksia* and *Dryandra* inflorescences, and other floral types, were made in this study by applying appropriate conversion factors to individual inflorescence counts. Counts for *Banksia attenuata* and *Banksia hookeriana* were arbitrarily multiplied by 100, those for *B. leptophylla*, and *Banksia candolleana* by 50, and for *Dryandra* species and *Grevillea eriostachya* (which has several flowers within one flower head) by 10.

The occurrence of reptiles, frogs and other mammals that are considered to use insects as a major component of their diet was compared with the supply of invertebrates at each site. Information relating to the invertebrates present at Sites 2, 3, 4 and 5 in January and March 1988 was taken from a study conducted by Hoyle (1988).

5.3 Results

5.3.1 Sources of food used by *Tarsipes rostratus* and honeyeaters: indirect evidence

Vertebrates whose pollen smears contained more than ten grains for particular plant species were considered to be significant pollen vectors for those species. Pollen counts for these plants were totalled for each survey month at each site, and expressed as percentages of the total number of pollen grains counted (Appendices 5 and 6). Data for all honeyeater species were pooled. Although both honeyeaters and *Tarsipes rostratus* carried pollen from the same plant species, they rarely carried the same dominant pollen (30% or more of the pollen grains counted) within any survey month (Tables 9 and 10). Exceptions occurred in March, when both honeyeaters and *T. rostratus* carried heavy loads of *Banksia leptophylla* at Site 3, and in May, when *Calothamnus sanguineus* pollen was dominant on both groups at Site 1.

Dominant pollen on smears collected from honeyeaters came from *Adenanthos cygnorum*, *C. sanguineus* and *Banksia hookeriana*, while for *T. rostratus* it was from *Eucalyptus todtiana*, *Eucalyptus tetragona*, *Banksia attenuata*, *B. leptophylla*, *Banksia grossa*, *Banksia candolleana*, *Dryandra sp*. unid. and *Dryandra nivea*.

Only two faecal samples, taken in November, were collected from *T. rostratus*. *B. attenuata* was dominant in these, as was the case with pollen smears taken at the same. Some pollen from *Beaufortia elegans* and *Dryandra* sp. unid. was also present. The pollen types present in faecal samples from honeyeaters were similar to those in facial smears (Appendix 7). There was a preponderance of pollen from small insect-pollinated flowers such as *Astroloma microdonta* in samples taken from *Phylidonyris melanops* in May at Site 1, and *Acacia* sp. in samples from *Phylidonyris nigra* in November at Site 5. Pollen from plant species such as *Jacksonia floribunda* and species of Asteraceae, normally thought to be insect-pollinated, was present in both facial and faecal material.

Pollen from *Dryandra nivea* (consumed by *P. nigra* in May at Sites 3, 4 and 5), *Banksia candolleana* (consumed by *Lichmera indistincta* in July at Site 3) and *Banksia grossa* (consumed by *P. melanops* in March at Site 4) was generally more abundant in faeces than in facial smears.

Table 9: Monthly variations in the relative abundance of pollen in smears taken from the heads of *Tarsipes rostratus* (Honey Possum) at each site during the study period.

Plant species	Site	January	March	May	July	September	November
Banksia attenuata	1						**xxxxxxx**
	4	xxxxxxx					**xxxxxxx**
	5						**xxxxxxx**
Banksia leptophylla	1		**xxxxxxx**				
	2		xxxxxxx				
	3		**xxxxxxx**				
Banksia grossa	1	xxxxxxx		xxxxxxx			
	2	xxxxxxx					
	3	xxxxxxx					
	4			**xxxxxxx**	**xxxxxxx**		
	5	xxxxxxx			xxxxxxx		xxxxxxx
Banksia candolleana	4				**xxxxxxx**		
	5				**xxxxxxx**		
Dryandra sp. unid.	1	**xxxxxxx**		xxxxxxx			
	2	**xxxxxxx**	**xxxxxxx**				
	3	xxxxxxx	xxxxxxx				
	4			xxxxxxx		xxxxxxx	
	5	xxxxxxx					
Dryandra nivea	1			**xxxxxxx**			
	4			**xxxxxxx**		xxxxxxx	
	5				xxxxxxx	**xxxxxxx**	
Adenanthos cygnorum	1		xxxxxxx				
	3		xxxxxxx				
Eucalyptus todtiana &/or *E. tetragona*	1	**xxxxxxx**					
	2	xxxxxxx					
	3	**xxxxxxx**	**xxxxxxx**				
	4	**xxxxxxx**					
	5	**xxxxxxx**					
Calothamnus sanguineus	1			xxxxxxx			
	5					**xxxxxxx**	
Verticordia grandis	4					**xxxxxxx**	
	5					xxxxxxx	
Verticordia densiflora	1	xxxxxxx					
	2	xxxxxxx					
	3	xxxxxxx					**xxxxxxx**
Beaufortia elegans	1	xxxxxxx					
	4						xxxxxxx
	5						xxxxxxx
Beaufortia bracteosa	1		xxxxxxx				

xxxxxxx pollen type is >10% of pollen counted/survey month.
xxxxxxx pollen type is >30% of pollen counted/survey month.

Table 10: Monthly variations in the relative abundance of pollen in smears taken from the heads of honeyeaters at each site during the study period.

Plant Species	Site	January	March	May	July	September	November
Adenanthos cygnorum	1	**xxxxxxx**		xxxxxxx	**xxxxxxx**	xxxxxxx	**xxxxxxx**
	2						xxxxxxx
	3	**xxxxxxx**	**xxxxxxx**			**xxxxxxx**	**xxxxxxx**
	4	**xxxxxxx**	**xxxxxxx**			**xxxxxxx**	
	5	**xxxxxxx**				xxxxxxx	**xxxxxxx**
Banksia hookeriana	1			xxxxxxx			
	2			xxxxxxx			
	3			xxxxxxx			
	4			**xxxxxxx**		xxxxxxx	
	5			**xxxxxxx**			
Banksia leptophylla	3		xxxxxxx				
	4		xxxxxxx				
Banksia menziesii	4		xxxxxxx				
Dryandra nivea	3			xxxxxxx	xxxxxxx		
	5			xxxxxxx			
Dryandra falcata	1					xxxxxxx	
	2						xxxxxxx
	3					xxxxxxx	
Dryandra sp. unid.	4		xxxxxxx				
Grevillea eriostachya	4						xxxxxxx
	5						xxxxxxx
Lambertia multiflora	2				xxxxxxx		
	3					xxxxxxx	
Beaufortia elegans	4						xxxxxxx
Calothamnus quadrifidus	1					xxxxxxx	**xxxxxxx**
	2						**xxxxxxx**
	3					xxxxxxx	xxxxxxx
	4					xxxxxxx	
	5					xxxxxxx	
Calothamnus sanguineus	1			**xxxxxxx**			
	2			**xxxxxxx**	**xxxxxxx**		
	3			**xxxxxxx**	**xxxxxxx**	xxxxxxx	
	4			**xxxxxxx**			
	5			xxxxxxx		**xxxxxxx**	
Calothamnus villosus	4						xxxxxxx
	5						xxxxxxx
Eucalyptus macrocarpa	3					xxxxxxx	**xxxxxxx**
Eucalyptus todtiana	5	xxxxxxx					
Mrytaceae species L	3		xxxxxxx				
	4		xxxxxxx				
Melaleuca trichophylla	4	xxxxxxx				xxxxxxx	
Verticordia densiflora	4						xxxxxxx
Verticordia grandis	4						xxxxxxx
	5						xxxxxxx
Jacksonia floribunda	1			xxxxxxx			
	2			xxxxxxx			
	3			xxxxxxx			
Astroloma microdonta	1			xxxxxxx			

xxxxxxx pollen type is >10% of pollen counted/survey month.
xxxxxxx pollen type is >30% of pollen counted/survey month.

5.3.2 Plant species used as a source of nectar by honeyeaters: direct evidence

Direct observation of honeyeaters identified several important food sources that were not implicated on the basis of pollen grain evidence. Among these were: *E. todtiana* at Sites 4 and 5, and *E. tetragona* at Site 1, in January; *Lambertia multiflora* at Site 1 in July and September, and Sites 3 and 4 in September; and *Grevillea eriostachya*, which was foraged on at various times of the year (Figures 34 and 35). Foraging observations for each honeyeater species known to visit *A. cygnorum, Calothamnus* species, *E. todtiana* and/or *E. tetragona, B. hookeriana and L. multiflora* indicate that these birds feed at particular plant species over a greater number of months and at more sites than is suggested by pollen smear data, although the picture is to some extent affected by sample size (Figures 36-38). It would appear as if *Calothamnus* species during the winter to spring months, *B. hookeriana* during the autumn to early spring months, *Eucalyptus* species in summer and *A. cygnorum* during the spring to autumn months are important food sources for honeyeaters.

In January, the main species visited at Sites 1 and 3 was *A. cygnorum*, with *E. tetragona* also popular at Site 1 and *E. todtiana* at Sites 4 and 5. *A. cygnorum* continued to be important at Sites 1 and 3 in March, with *B. hookeriana* becoming significant at Site 2. In May, *B. hookeriana* was visited frequently at Sites 2, 3 and 4, *C. sanguineus* at Sites 1 and 3, and *B. leptophylla* at Site 5. *B. hookeriana* continued to be important at Sites 2 and 4 in July and September, whereas *L. multiflora* became progressively more popular at Sites 1 and 3 in these months. *G. eriostachya* was frequently visited at Sites 3 and 5 in July, and at Site 4 in September. In September, *Dryandra falcata* was also important at Site 1, and *Calothamnus villosus* at Site 5. *A. cygnorum* once again became an important nectar-source at Sites 1, 3, 4 and 5 in November, with *Calothamnus quadrifidus* the most frequently visited species at Site 2.

In addition to the overall differences mentioned above, honeyeaters species varied with respect to their preferences for particular plants. For example, at Site 1 in January, *P. nigra* and *P. melanops* mainly visited *A. cygnorum*, while *L. indistincta* fed predominantly on *E. tetragona*. At Site 3 during the same month, *L. indistincta* spent some time feeding at *A. cygnorum*, although it more frequently visited *E. tetragona*. *P. nigra* and *P. melanops* fed predominantly at *L. multiflora* at Site 1 in July, while *L. indistincta* was attracted more often to *Calothamnus* sp. This pattern changed in September, when *D. falcata* was in flower and *P. nigra* was the most active honeyeater at that species, yet *P. melanops* and *L. indistincta* fed predominantly at *L. multiflora*.

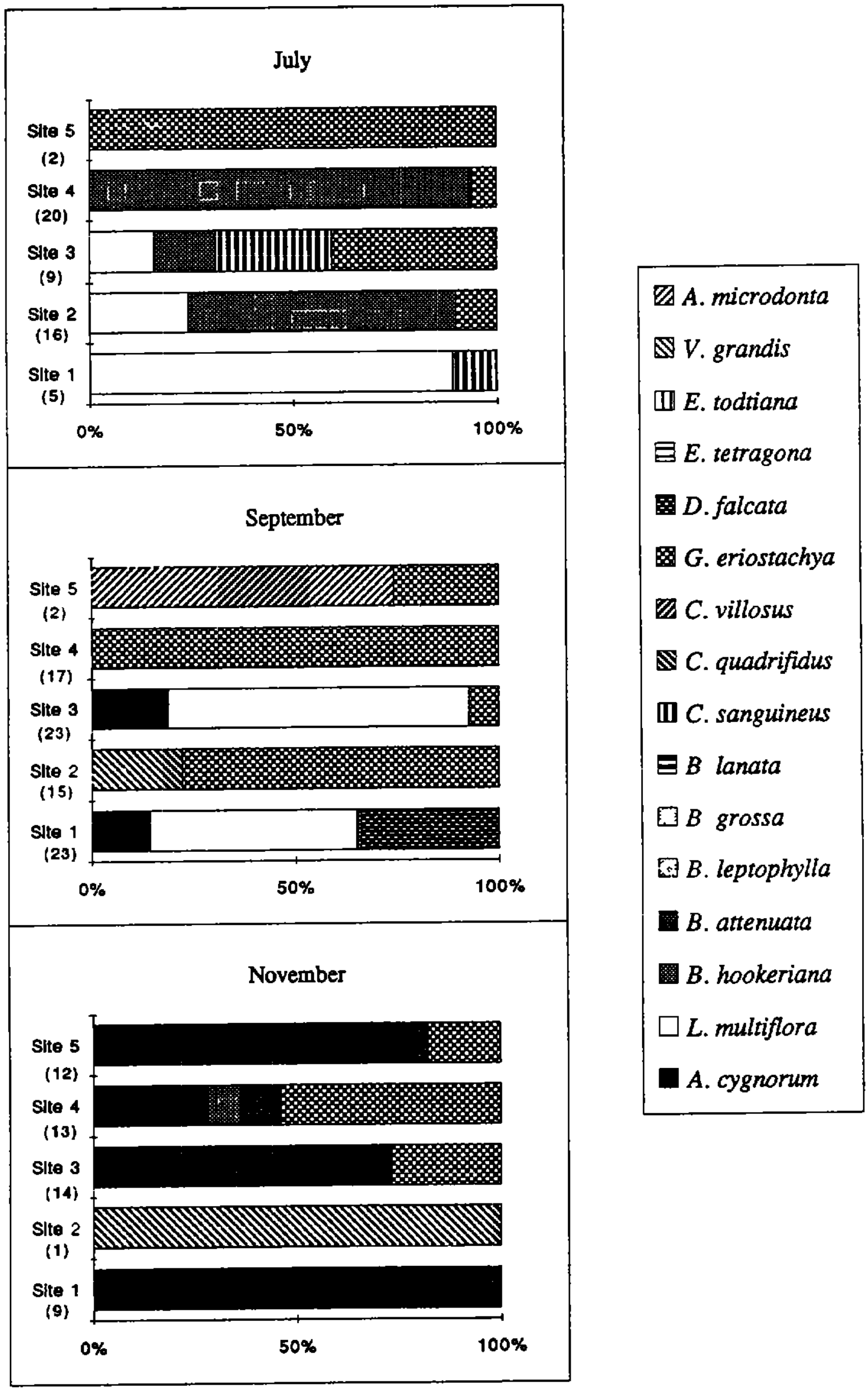

Figure 34: Percentages of total foraging time spent by honeyeaters at the flowers of various plant species at each site during visits in 1987. Numbers of observations are given in parentheses.

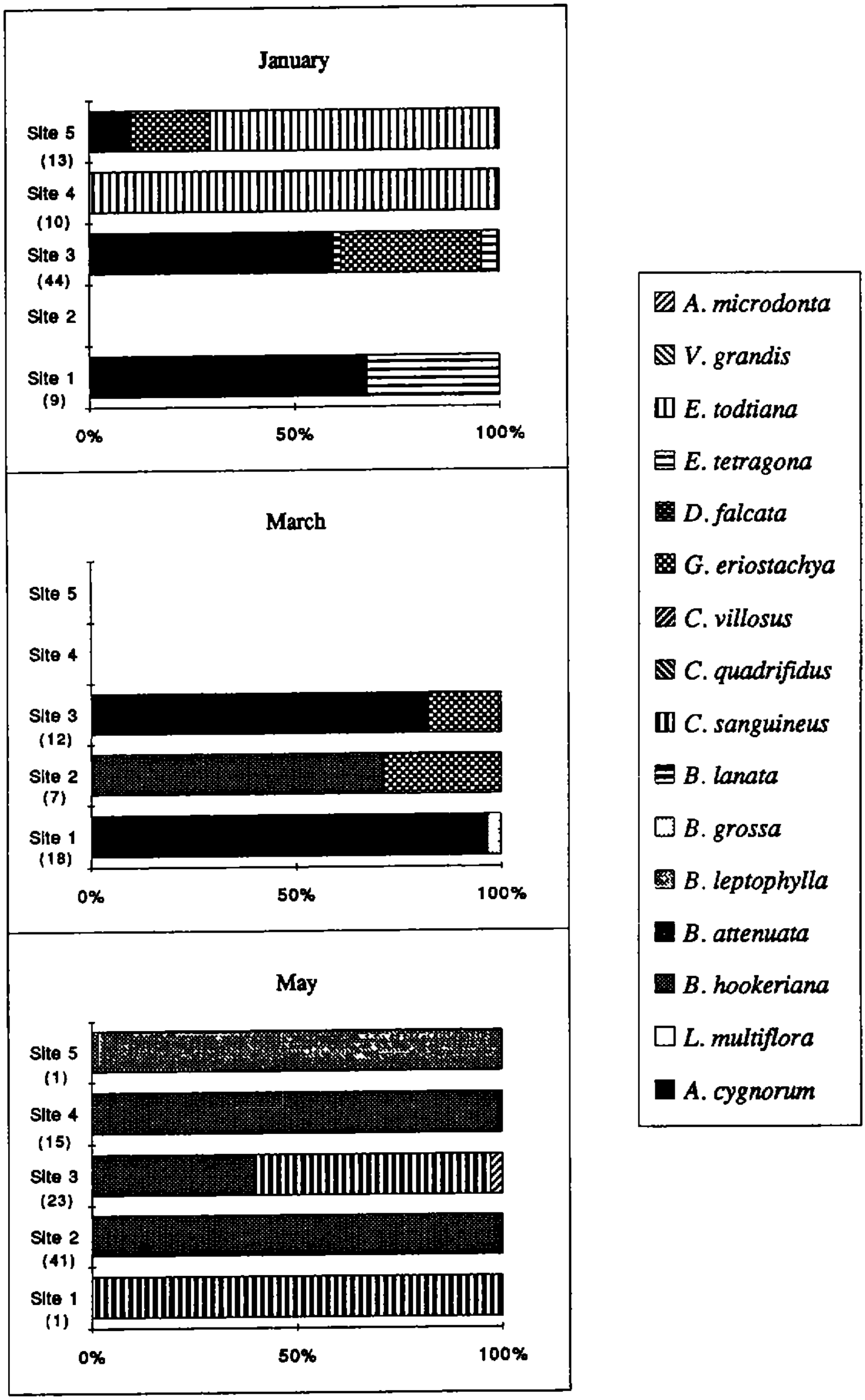

Figure 35: Percentages of total foraging time spent by honeyeaters at the flowers of various plant species at each site during visits in 1988. Numbers of observations are given in parentheses.

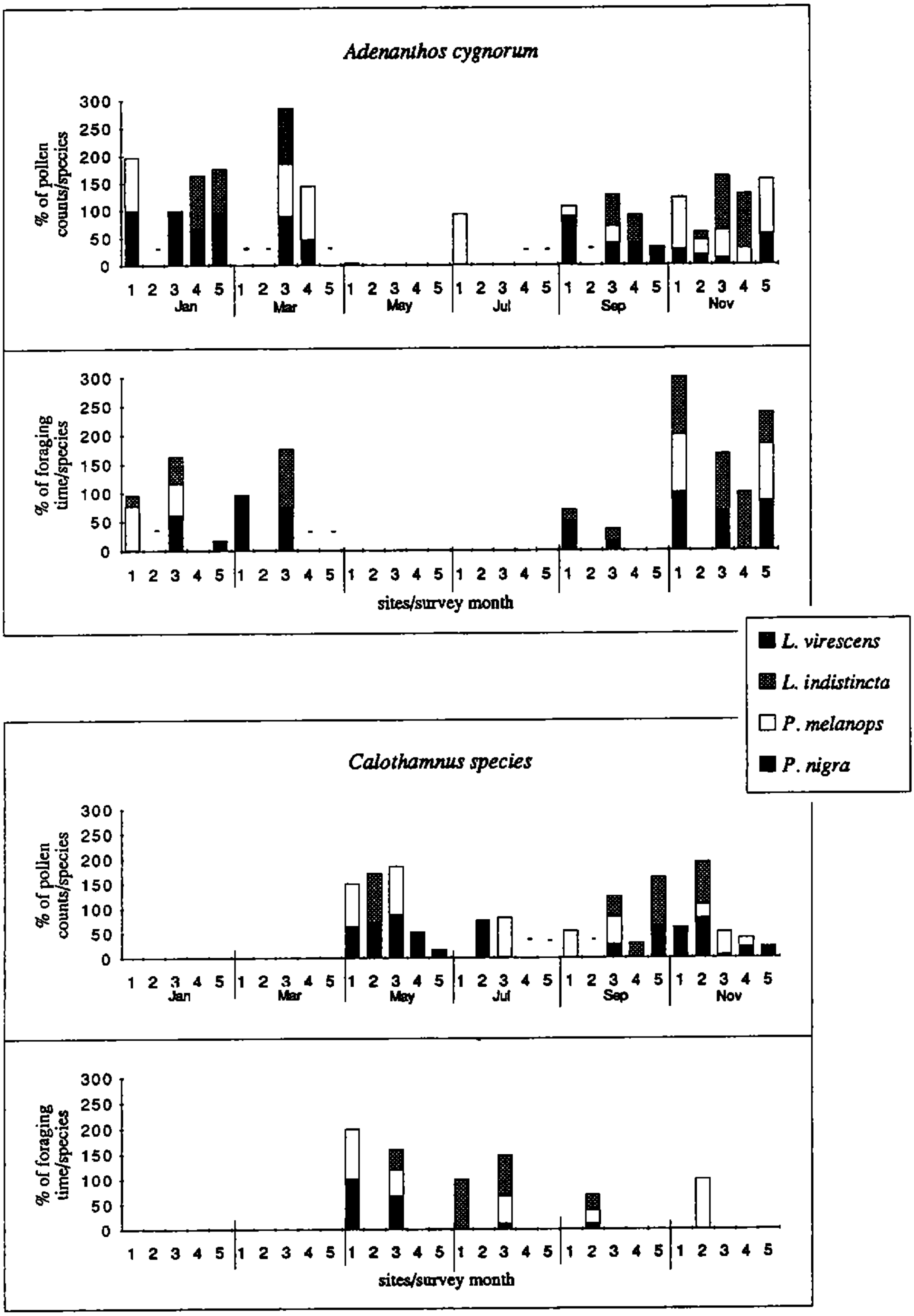

Figure 36: Site- and survey-related differences in percentages of total pollen loads detected on honeyeaters that were from *Adenanthos cygnorum* and *Calothamnus* species, and percentages of total foraging time that these birds spent visiting flowers of the same species. "-" indicates that data are not available for comparison.

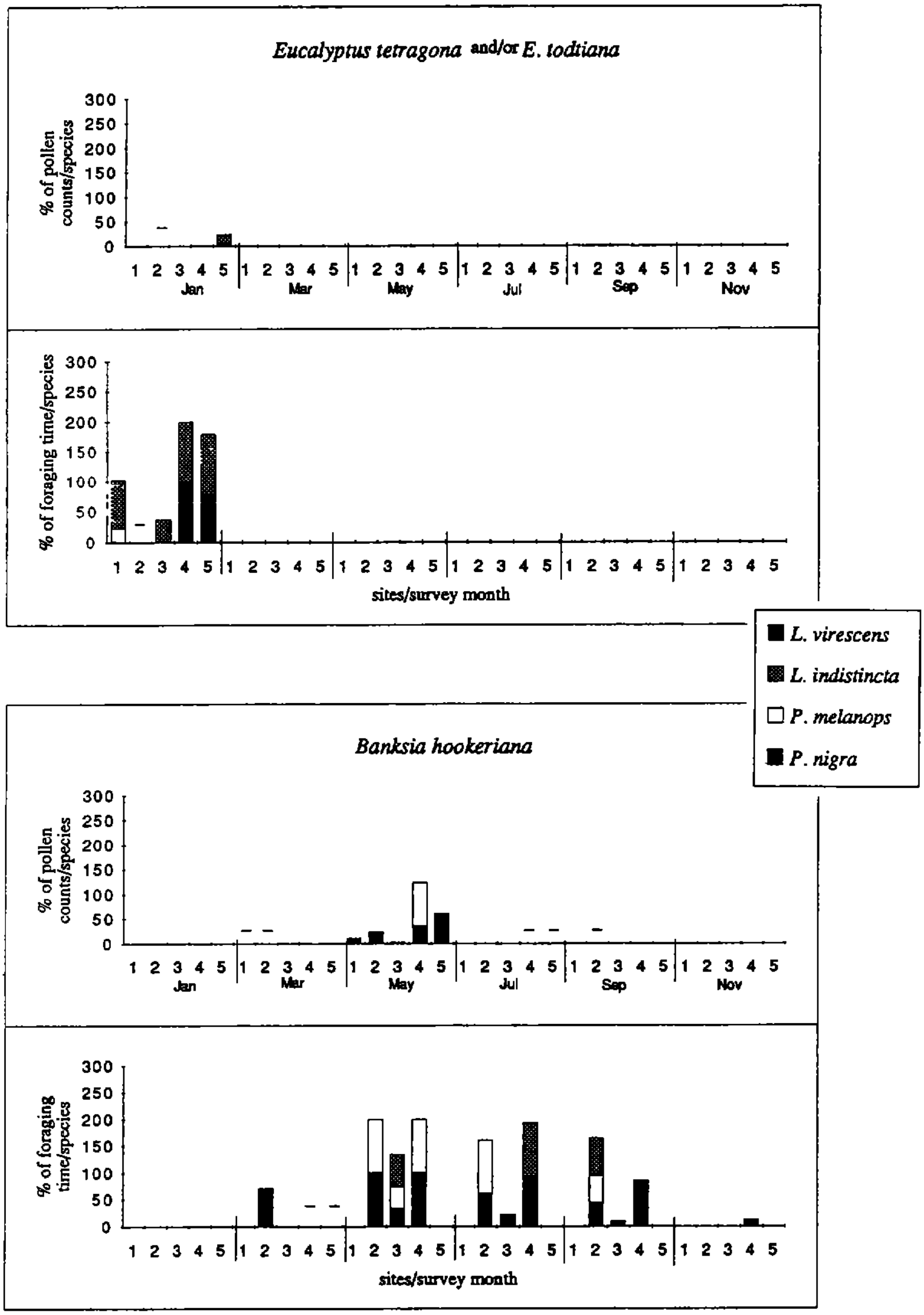

Figure 37: Site- and survey-related differences in percentages of total pollen loads detected on honeyeaters that were from *Eucalyptus tetragona* /*E. todtiana* and *Banksia hookeriana*, and percentages of total foraging time that these birds spent visiting flowers of the same species. "-" indicates that data are not available for comparison.

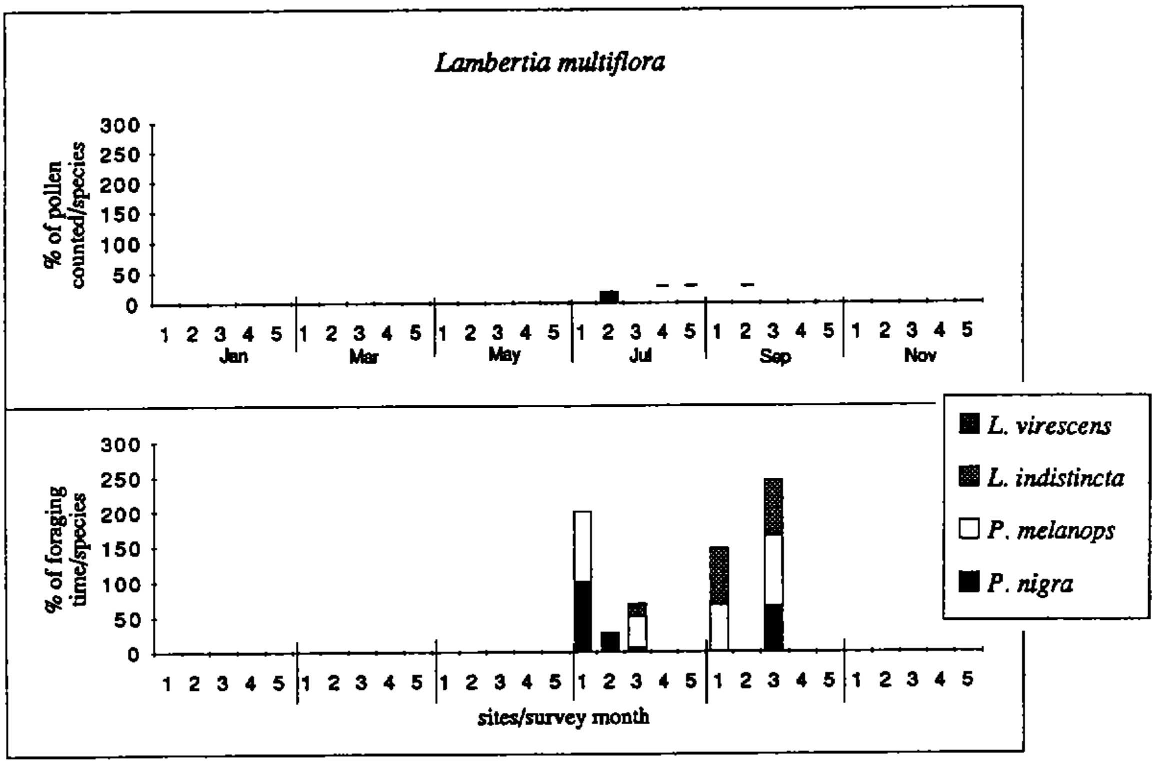

Figure 38: Site- and survey-related differences in percentages of total pollen loads detected on honeyeaters that were from *Lambertia multiflora*, and percentages of total foraging time that these birds spent visiting flowers of the same species. "-" indicates that data are not available for comparison.

Plant species considered to be important as food sources for honeyeaters and *T. rostratus* on the basis of direct and indirect evidence during each survey month are indicated in Table 11. Despite the presence of its pollen in smears taken from honeyeaters, no plant species has been listed unless that species was known to have been in flower at the site where the smears were obtained.

5.3.3 Comparison of honeyeater and flower abundance at natural and rehabilitated sites

Honeyeater abundance peaked in July 1988 at each site. This time of year did not appear to coincide with peak flower abundance for any particular plant species, although the increase in honeyeater abundance from March to July coincided with a general increase in the number of species in flower (Figures 39 and 40). Sites 2 and 4 had relatively large numbers of honeyeaters in May, compared to other sites, a result that may have been attributable to the strong flowering of *B. hookeriana*. Honeyeater abundance dropped in September and November at each site, despite the fact that floral abundance was high for species such as *B. attenuata* at Sites 1 and 2, and *A. cygnorum* at Sites 1, 2 and 3.

Table 11: Major nectar sources for *Tarsipes rostratus* and honeyeaters during each survey month at each site. Plant species known to be in flower at particular sites, but for which no foraging data were available at those sites, have been listed (underlined) in instances where evidence obtained elsewhere indicates that they are likely to be important nectar sources. The relative abundance of these plants has been estimated as low (L), medium (M) or high (H). In other instances, general comments about the intensity of flowering have been made.

January	March	May	July	September	November
Tarsipes rostratus					
SITE 1 *Dryandra sp. unid.* *Eucalyptus tetragona*	*Banksia leptophylla*	*Dryandra nivea* *Calothamnus sanguineus*	Low flowering	Low flowering	*Banksia attenuata*
SITE 2 *Dryandra sp. unid.*	*Dryandra sp. unid.*	Low flowering	Low flowering	Calothamnus quadrifidus (H)	Banksia attenuata (H) Calothamnus quadrifidus (M)
SITE 3 *Eucalyptus tetragona*	*Banksia leptophylla* *Eucalyptus tetragona* *Dryandra sp. unid.*	Calothamnus sanguineus (H)	Calothamnus sanguineus (M)	Low flowering	*Verticordia densiflora*
SITE 4 *Eucalyptus todtiana*	Banksia leptophylla (L)	*Banksia grossa* *Dryandra nivea*	*Banksia grossa* *Banksia candolleana*	*Verticordia grandis*	*Banksia attenuata*
SITE 5 *Eucalyptus todtiana*	Banksia leptophylla (L)	Banksia candolleana (M)	*Banksia candolleana*	*Dryandra nivea* *Calothamnus sanguineus*	*Banksia attenuata*
Honeyeaters					
SITE 1 *Adenanthos cygnorum* *Eucalyptus tetragona*	*Adenanthos cygnorum* *Banksia grossa*	*Calothamnus sanguineus*	*Lambertia multiflora* *Calothamnus sanguineus*	*Lambertia multiflora* *Dryandra falcata* *Adenanthos cygnorum*	*Adenanthos cygnorum*
SITE 2 Low Flowering	*Banksia hookerana* *Grevillea eriostachya*	*Banksia hookerana*	*Banksia hookerana* *Lambertia multiflora*	*Banksia hookerana* *Calothamnus quadrifidus* *Grevillea eriostachya*	*Calothamnus quadrifidus*
SITE 3 *Adenanthos cygnorum* *Eucalyptus tetragona* *Banksia lanata* *Grevillea eriostachya*	*Adenanthos cygnorum* *Banksia leptophylla* *Grevillea eriostachya*	*Calothamnus sanguineus* *Banksia hookerana*	*Calothamnus sanguineus* *Banksia hookerana* *Lambertia multiflora*	*Adenanthos cygnorum* *Lambertia multiflora* *Banksia attenuata* *Grevillea eriostachya*	*Adenanthos cygnorum* *Eucalyptus macrocarpa* *Grevillea eriostachya*
SITE 4 *Eucalyptus todtiana* *Adenanthos cygnorum*	*Banksia menziesii* *Banksia leptophylla*	*Banksia hookerana* *Calothamnus sanguineus*	*Banksia hookerana* *Grevillea eriostachya*	*Banksia hookerana* *Grevillea eriostachya*	*Grevillea eriostachya* *Adenanthos cygnorum* *Banksia attenuata* *Banksia hookeriana*
SITE 5 *Eucalyptus todtiana* *Adenanthos cygnorum* *Grevillea eriostachya*	Banksia leptophylla (L)	*Banksia hookerana* *Banksia leptophylla*	*Grevillea eriostachya* Banksia leptophylla (H)	*Calothamnus villosus* *Grevillea eriostachya* *Adenanthos cygnorum*	*Adenanthos cygnorum* *Banksia attenuata* *Grevillea eriostachya*

Honeyeater densities recorded at Site 3 were almost three times those for other sites. *A. cygnorum* appeared to be the main source of nectar at this site, producing more flowers than at other sites , e.g., approximately 22,700 flowers at Site 3, compared with 2,700 flowers at Site 1. A decrease in floral abundance for this species at Site 3 in March coincided with a drop in honeyeater numbers. Other plants that were probably important at Site 3 included *E. tetragona* and *C. sanguineus*, which produced large numbers of flowers per plant and were either tall trees or large shrubs. The same species occurred as much smaller plants at other sites, and consequently produced fewer flowers.

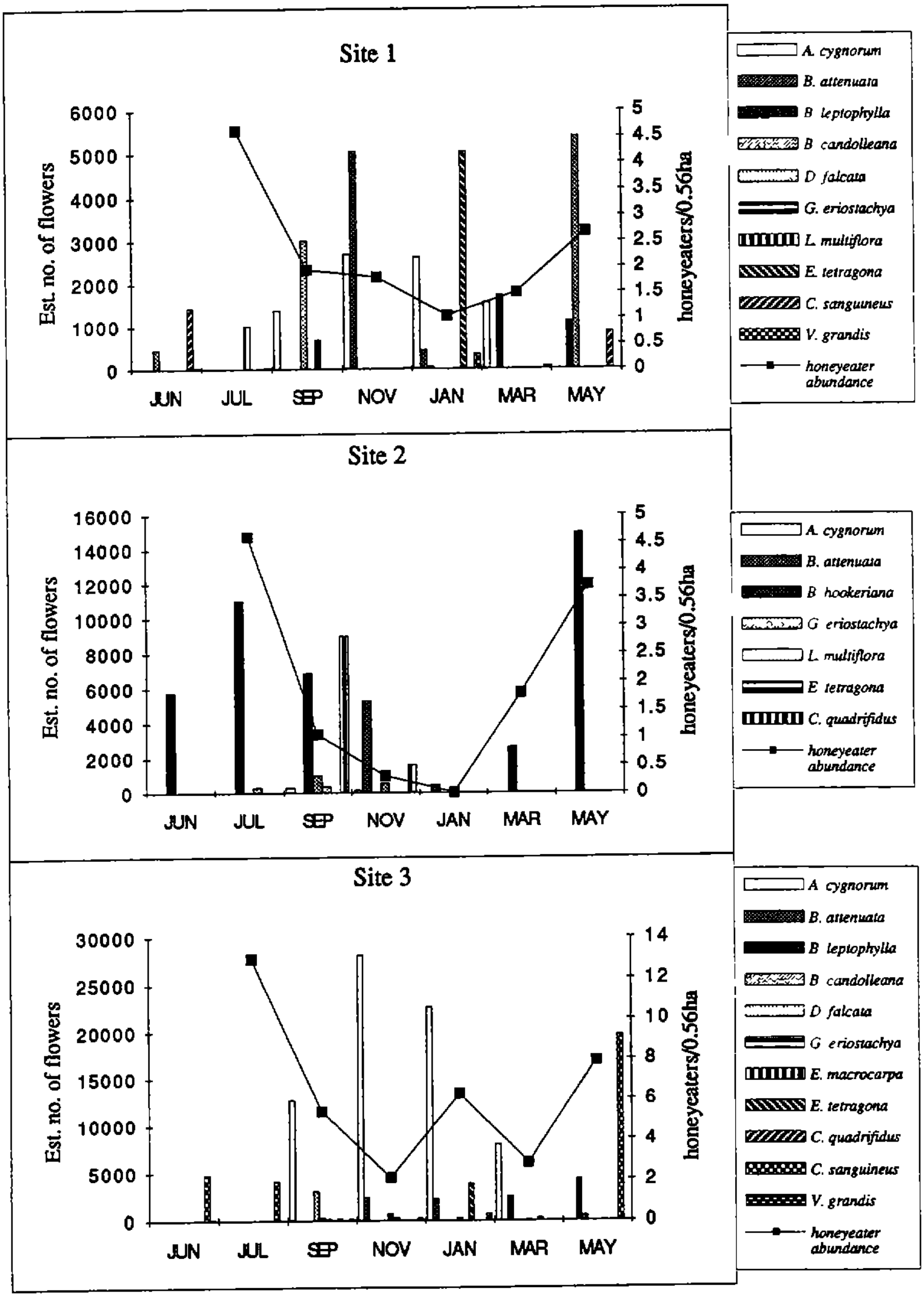

Figure 39: Honeyeater densities and floral abundances for major nectar-producing plants at Sites 1, 2 and 3 during the study period. The number of flowers at each site has been estimated on the basis of flower counts (June 1987 to May 1988) and plant density estimates.

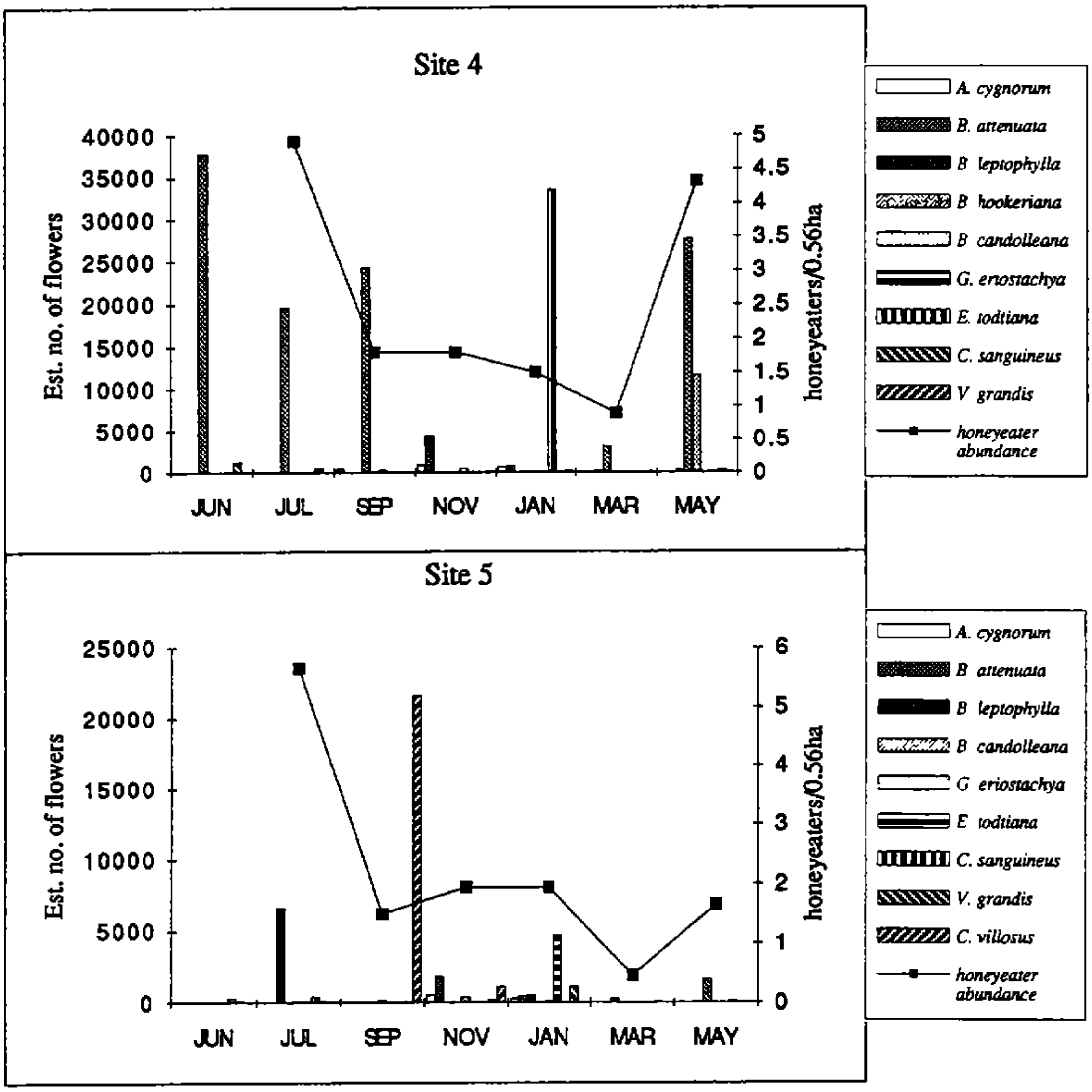

Figure 40: Honeyeater densities and floral abundances for major nectar-producing plants at Sites 4 and 5 during the study period. The number of flowers at each site has been estimated on the basis of flower counts (June 1987 to May 1988) and plant density estimates.

Floral abundances comparable to those observed at Site 3 were only recorded at Site 4 for *B. hookeriana*, and at Site 5 for *C. villosus* . Few flowers were counted at Site 1 in comparison with Sites 3, 4 and 5, although honeyeater densities were similar at Sites 1, 4 and 5. At Site 1, *P. melanops* was often the dominant honeyeater, whereas *P. nigra* tended to be dominant at Sites 2, 4 and 5 (see Chapter 4).

Site 3 had the greater number of flowering species of all the sites, including all those that also occurred at Sites 1, 4 and 5. In contrast, Site 2 had very few of the major flowering species. Although Site 2 had vegetation which was similar to that at Site 1 (situated ~20m to its east), its pattern of nectar supply was different. Flowering at Site 2 was minimal in January (*E. tetragona* was not yet flowering strongly and *A. cygnorum* was not present at this Site), and *C. quadrifidus* (which flowered in September and November) replaced the *C. sanguineus* (which flowered in May) that was typical of Site 1. In addition, *B. hookeriana* was the main flowering species at Site 2, but was not present at Site 1.

Quantitative descriptions of flowering phenology were not always established completely at each site. For instance, flowering appeared to be poor at Site 5 in May and June, although no flower counts were conducted for two plant species, *B. grossa* and *D. nivea*, that were in flower at this time. These two species may be important food sources for *T. rostratus*, since *B. grossa* pollen was present in smears in substantial amounts during May and July at Site 4, and *D. nivea* pollen in May at Sites 1 and 4, and in September at Site 5. *Dryandra* sp. unid., for which there were no flower counts, was also present in smears collected during March at Sites 1, 2 and 3, and during January at Sites 1 and 2.

5.3.4 Potential food sources for *Sminthopsis granulipes*, *Pseudomys albocinereus* and *Mus musculus*: indirect evidence.

Sminthopsis granulipes (1-61 pollen grains, with one count of 79), *Pseudomys albocinereus* (1-36 pollen grains, with one count of 80) and *Mus musculus* (1-29 pollen grains) carried very small pollen loads compared with *T. rostratus* (1-349 pollen grains, with one count of 632). Nevertheless, the dominant pollen types (greater than 30% of all pollen grains counted for a particular mammalian species/site/month) were very similar for all species (Table 12). For instance, significant quantities of *B. grossa*, *B. candolleana*, *D. nivea* and *Dryandra* sp. unid pollen were carried by the four species. Pollen from species of *Calothamnus* and *Eucalyptus* were also usually present. Individual pollen counts for the three murid species are detailed in Appendices 7, 8 and 9.

Faecal samples produced by *S. granulipes* contained fewer than five pollen grains, those by *P. albocinereus* under 15 grains (except for one sample with 41 *B. candolleana* grains). Half of the faecal samples from *M. musculus* contained no pollen grains, although others had 2-68 pollen grains, with one having 319 grains, predominantly from *A. cygnorum* and *C. sanguineus*.

5.3.5 Use of arthropods by *Sminthopsis granulipes*, *Pseudomys albocinereus* and *Mus musculus*

Because relatively few faecal samples were obtained, the percentage of samples containing arthropod material have been grouped together either into months for all sites

(Table 13) or sites for the total year (Table 14). *P. albocinereus* samples collected in July had a high incidence of arthropods (89%), although the incidence was low in November (31%) The overall figure for July may be artificially high, as eight of the nine faecal samples collected were from Sites 4 and 5, where the incidence of arthropod remains tended to be higher than at Sites 1, 2 and 3. In November, faecal samples were collected from all sites, and the incidence of those containing arthropods was low for all sites.

Table 12: Incidence of pollen in smears taken from the fur of *Sminthopsis granulipes*, *Pseudomys albocinereus* and *Mus musculus*.

Plant Species	Site	January	March	May	July	September	November
Banksia attenuata	1	+S					
	4	+P				+S	xxP
	5						+S
Banksia leptophylla	1		xxP		+S	+P	
	4				+P		
	5				+P		
Banksia grossa	1	xxS	+P	+P	xxS +M	+P	**xxSP+M**
	2	+M			+M		+P
	3	+M					**xxP+M**
	4	+P		xxS	+M +S	+S	+S +P
	5	xxP +M		+M	+M	+M +P	+M
Banksia candolleana	1				xxSxxM		
	4			**xxM**	+S+P+M		
	5				**xxPxxM**	xxM	
Dryandra sp. unid.	1	xxS			+S +M	+P	+S +M
	2						+M
	3					+M	
	4	xxP		xxS +P	xxP +M		+S
	5	+M		+S	+P +M	+M	+S +M
Dryandra nivea	1			+M	xxS +M		
	4			+S	+P		
	5			+S +M			
Dryandra falcata	1	+S			+M		
	3					**xxM**	
	5					+M	
Adenanthos cygnorum	1		+P				+S +P
	4	+P					+S
	5	+P				+P	xxS +P+M
Eucalyptus tetragona	1	**xxP+S**	+P				
Calothamnus sanguineus	1			+M	+M		+P
	2						+P +M
	3						+P
	4			+S+P+M	+P	xxS +P	xxP
	5					+P +M	+P
Calothmanus quadrifidus	1						**xxM**
	2	+M					+M
	3	+M					
Verticordia muelerina?	1						+S
	3						+P
	4					xxS	

+ = pollen type present, butwith fewer than 10 pollen grains and/or less than 30% of total pollen counts
xx = pollen type present, constituting 30-69% of total pollen count (bold type = 70-100% of total load)
S = Sminthopsis granulipes; P = Pseudomys albocinereus; M = Mus musculus

M. musculus appeared to have a higher incidence of arthropod remnants in faecal samples than *P. albocinereus*, although this result may have been biased because of the small sample size for *M. musculus*. Arthropod remains were less common for the latter species in March and May than at other times.

Table 13: Percentage incidence of faecal samples containing arthropod remains collected from *Pseudomys albocinereus*, *Sminthopsis granulipes* and *Mus musculus* during each survey month.

Month	No. of slides	Definite remains no. slides	%	Possible remains no. slides	%	Total remains no. slides	%
Pseudomys albocinereus							
July	9	1	11.1	7	77.8	8	88.9
September	3	0	0.0	0	0.0	0	0.0
November	13	1	7.7	3	23.1	4	30.8
January	3	0	0.0	0	0.0	0	0.0
March	5	1	20.0	2	40.0	3	60.0
May	6	2	33.3	2	33.3	4	66.7
TOTAL	39	5	12.8	14	35.9	19	48.7
Sminthopsis granulipes							
July	3	0	0.0	0	0.0	0	0.0
September	0	0		0		0	
November	11	6	54.5	4	36.4	10	90.9
January	4	3	75.0	1	25.0	4	100
March	1	1	100.0	0	0.0	1	100
May	3	2	66.7	1	33.3	3	100
TOTAL	22	12	54.5	6	27.3	18	81.8
Mus musculus							
July	5	4	80 0	0	0.0	4	80.0
September	4	2	50 0	2	50.0	4	100
November	2	1	50.0	1	50.0	2	100
January	2	1	50.0	1	50.0	2	100
March	2	0	0.0	1	50.0	1	50.0
May	2	0	0.0	0	0.0	0	0.0
TOTAL	17	8	47.1	5	29.4	13	76.5

90-100% of the faecal samples from *S. granulipes* contained arthropod remnants during each survey month other than September, when no data were available. A similarly high incidence of remnants was detected at each of the undisturbed Sites 1, 4 and 5 (no *S. granulipes* were trapped at the rehabilitated sites).

Table 14: Percentage incidence of faecal samples containing arthropod remains collected from *Pseudomys albocinereus*, *Sminthopsis granulipes* and *Mus musculus* at each site.

Site	No. of slides	Definite remains no. slides	%	Possible remains no. slides	%	Total remains no. slides	%
Pseudomys albocinereus							
Site 1	10	0	0.0	3	30.0	3	30.0
Site 2	1	0	0.0	0	0.0	0	0.0
Site 3	3	1	33.3	0	0.0	1	33.3
Site 4	20	3	15.0	9	45.0	12	60.0
Site 5	5	1	20.0	2	40.0	3	60.0
TOTAL	39	5	12.8	14	35.9	19	48.7
Sminthopsis granulipes							
Site 1	14	10	71.4	3	21.4	13	92.9
Site 2	0	0		0		0	
Site 3	0	0		0		0	
Site 4	6	4	66.7	2	33.3	6	100.0
Site 5	2	1	50.0	1	50.0	2	100.0
TOTAL	22	15	68.2	6	27.3	21	95.5
Mus musculus							
Site 1	4	2	50.0	1	25.0	3	75.0
Site 2	2	1	50.0	0	0.0	1	50.0
Site 3	1	1	100.0	0	0.0	1	100.0
Site 4	6	2	33.3	3	50.0	5	83.3
Site 5	4	2	50.0	1	25.0	3	75.0
TOTAL	17	8	47.1	5	29.4	13	76.5

5.3.6 Seasonal variations in hawking, aerial feeding and ground foraging by birds

The frequency of hawking for arthropods by the three main honeyeater species was highest at Site 3, and least at Site 5 (Figure 41). Hawking in May and September at Sites 3 and 4 was undertaken mainly by *P. nigra* (80% and 53%, respectively), in July at Sites

1, 2 and 3 predominantly by *P. melanops* (56%), and in November at Sites 3 and 5 mainly by *L. indistincta* (54%).

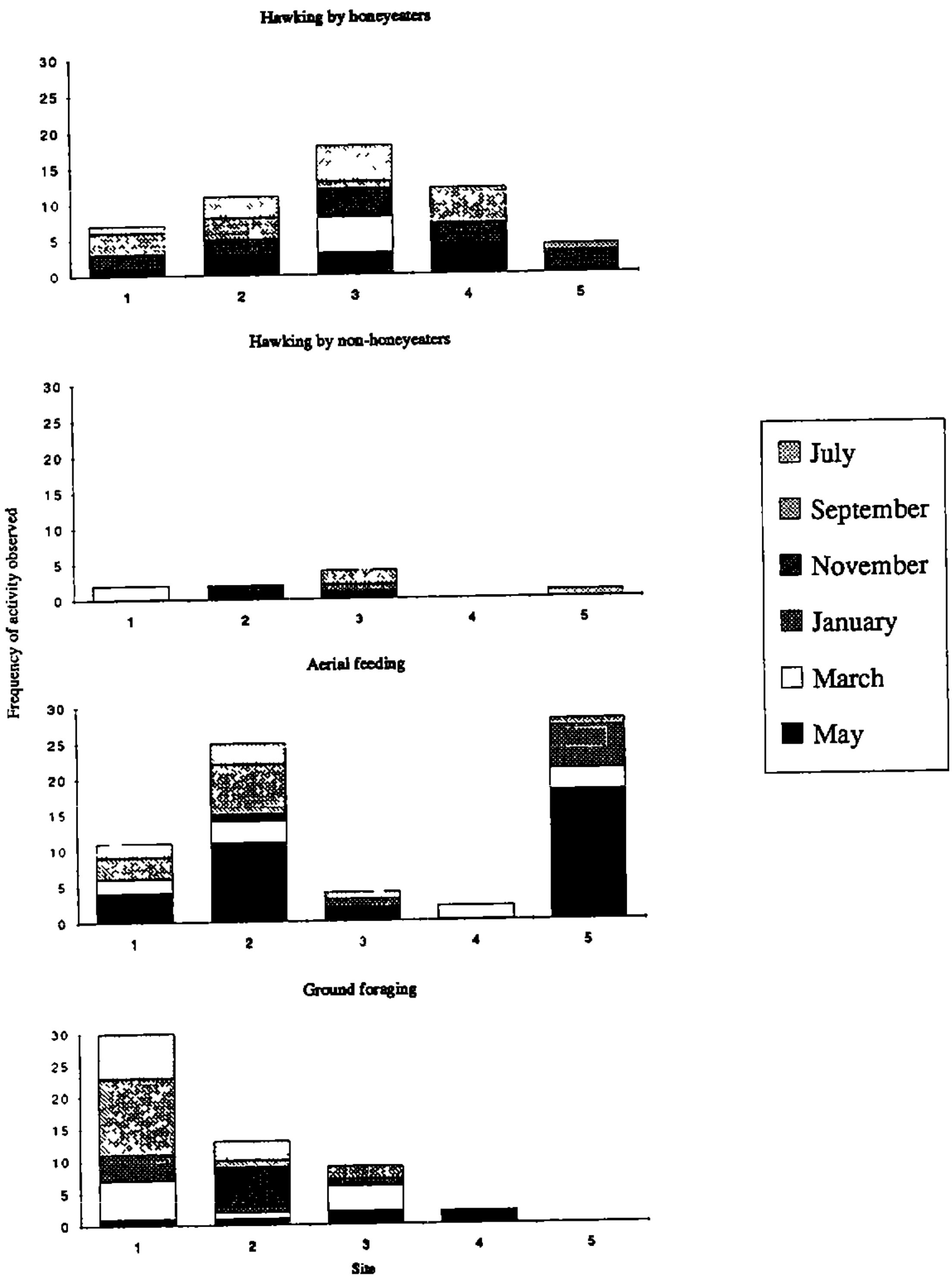

Figure 41: Frequencies of hawking by honeyeaters and non-honeyeaters, aerial feeding by swallows, woodswallows and bronze-cuckoos, and ground feeding by fairy-wrens, pigeons, wagtails, field wrens and honeyeaters.

Hawking by other species such as *Rhipidura leucophrys* and *Malurus leucopterus* occurred at Sites 1 and 2, by *Malurus lamberti* at Site 5, and *Chrysococcyx basalis* at Site 3. The latter species was also observed feeding on the ground.

Aerial feeding activity was greatest at Sites 1, 2 and 5 (Figure 41), and was dominated by *Cheramoeca leucosternum* (86% of all aerial feeding observations), *Hirundo noexena* and *Artamus cinereus* (at Site 3).

Ground foraging was most prevalent at Site 1 (Figure 41), principally involving *M. leucopterus* and *Anthus novaeseelandiae* (Richard's Pipit). Other species involved at Site 1 were *Sericornis fuliginosus*, *Malurus splendens*, *P. melanops* and *Ocyphaps lophotes* (Crested Pigeon). *M. leucopterus* and *A. novaeseelandiae* were the only species observed feeding on the ground at Site 2. At Site 3, *A. novaeseelandiae*, *R. leucophrys* and *C. basalis* were the principal species involved, while *M. lamberti* was the only species observed ground-feeding at Site 4, and none were observed at Site 5.

5.4 Discussion

This study has demonstrated that a combination of pollen smear and foraging observation data should give a more reliable indication of the plant species preferred as food sources by honeyeaters than either measure on its own. Nevertheless, the two lines of evidence sometimes appear to be contradictory, and it is not always easy to determine which is correct. For example, honeyeaters carried light loads of *Lambertia multiflora* and *Eucalyptus* pollen, yet were frequently seen foraging at these species. This discrepancy may be explained by the fact that they release and deposit less pollen on honeyeaters than do the flowers of plants such as *Adenanthos cygnorum* and *Calothamnus sanguineus*. In contrast, contradictory evidence for *Grevillea eriostachya* may have occurred because of the ease with which foraging observations at the clusters of exposed flowers could be made. Unfortunately, only pollen smear data were gathered for small mammals in the Eneabba area, and caution must therefore be exercised when interpreting this information.

5.4.1 Comparison of plant species used as sources of food by honeyeaters and *Tarsipes rostratus*

Some investigators have suggested that differences in flower morphology, colour, scent, position on plant and pattern of nectar production have evolved as adaptations to different types of pollinators. For instance, it has been alleged that flowers pollinated by non-flying mammals occur close to the ground, are relatively inconspicuous, produce concentrated nectar and have a strong odour (Rourke & Weins 1977; Carpenter 1978; Holm 1978). In contrast, exposed flowers that are brightly-coloured and have little aroma have been considered more likely candidates for pollination by birds (Raven 1972). Recent studies have shown, however, that pollination syndromes such as these are by no means universal, with birds and mammals visiting flowers that have a broad range of morphological and other attributes (Hopper 1980; Turner 1982; Collins & Rebelo 1987; Collins *et al*. 1990).

Evidence obtained in this study has shown that honeyeaters and *Tarsipes rostratus* carried pollen from similar plant species. Nevertheless, the dominant types present in smears were usually different, and sometimes included pollen from species whose attributes more or less conformed to the alleged bird or mammalian pollination syndromes. For example, the most abundant pollen in smears taken from honeyeaters was derived from *A. cygnorum*, *L. multiflora*, *G. eriostachya*, *Dryandra falcata* and *Banksia hookeriana*, each of which has small tubular flowers and/or flowers that occur terminally on branches at some distance from the ground. In contrast, the dominant pollen in smears taken from *T. rostratus* was from *Dryandra nivea*, *Dryandra* sp. unid. and *Banksia candolleana*, all of which have inflorescences situated close to the ground or within the shrub (Figure 42).

Several exceptions to the above pattern were observed, with *T. rostratus* and honeyeaters showing a preference for the same plant species. For instance, pollen from *Banksia leptophylla*, which has relatively inconspicuous inflorescences located within its canopy, was dominant in smears taken from *T. rostratus* and honeyeaters in March. Other plant species whose pollen was abundant on *T. rostratus* and honeyeaters were *Calothamnus* species, *Eucalyptus todtiana*, *Eucalyptus tetragona*, *Banksia grossa* and *Banksia attenuata* (Figure 43).

5.4.2 Relationship between honeyeater abundance and nectar availability

Although nectar is a major food source for most honeyeaters, detailed regional studies undertaken in Australia have not always shown a close correlation between honeyeater abundance and nectar availability (Pyke 1983; Collins *et al.* 1984; Collins & Newland 1986). Where populations included resident honeyeaters only, rather than a mixture of resident and transient birds, correlation tended to be more significant (Paton 1985). This observation is not surprising, since resident honeyeaters are often involved in breeding activity, and would thus be particularly dependent upon nectar as a source of energy Indeed, Paton (1985) and Pyke & Recher (1986) have shown that honeyeaters only nest in heathlands of south eastern Australia during autumn and/or spring, when there is a relatively abundant supply of nectar-energy.

(a)

(b)

Figure 42: Inflorescences of (a) *Dryandra nivea* and (b) *Banksia candolleana* that are visited by Tarsipes *rostratus* are situated close to the ground.

(a)

(b)

Figure 43: Inflorescences of (a) *Banksia leptophylla* (situated within the shrub) and (b) *Banksia attenuata* (presented in the outer canopy of the shrub) are visited by both *Tarsipes rostratus* and honeyeaters.

Evidence obtained during this study indicated that honeyeaters were nesting at Sites 1 and 3, and possibly also at Sites 4 and 5. For instance, active honeyeater nests were located, juvenile *Phylidonyris nigra* were observed during the winter and spring months, and juvenile *Phylidonyris melanops* during spring and summer (see Chapter 4). Nectar needed for the maintenance of adult and young birds must have been available at these times. Peak abundance of *P. nigra* in May and July 1988 coincided with the expected time of nesting activity for this species (Figures 39 and 40). Abundance for *P. melanops* and *Lichmera indistincta* was also greatest in July 1988. Low honeyeater numbers during the summer months coincided with the end of the breeding season and a period of minimal flower availability.

It appears likely that honeyeater abundance was higher in July 1988 than at the corresponding time in 1987. Although no bird census data are available for July 1987, low capture rates from mist-netting suggest that the honeyeater population size was smaller than in July 1988 (Figure 44). The likely increase in honeyeater abundance between years may have occurred in response to a rise in flower abundance that enabled these sites to support more resident and transient birds. Late spring rains experienced in 1987 (Figure 1) may have induced greater vegetative and flower bud growth in some plant species, and therefore led to increased flower abundance during the following year. Unfortunately, no flower counts were made in July 1988, thus precluding a direct comparison with honeyeater abundance.

5.4.3 Provision of a continuous supply of nectar

This study identified a wide range of plant species that were visited by vertebrates that are known to rely on pollen and/or nectar as sources of food. Sites differed with respect to the manner in which these resources were supplied. For example, most nectar tended to be supplied at Site 1 from September to May, when plant species such as *A. cygnorum*, *D. falcata*, *B. attenuata*, *E. tetragona*, *B. leptophylla* and *B. candolleana* were in flower. Peak nectar availability at Site 4 occurred from May to September, and was associated with the flowering of *Banksia hookeriana* and *B. candolleana*. At Site 5, the flowering of *B. leptophylla* and *Calothamnus villosus* generated relatively high nectar production in July and September. Although this is a simplification of the total picture, and ignores other significant flowering that occurred during survey months at each of these sites, it would seem as if the three main plant associations identified within Eneabba heathlands that are represented by these sites are necessary if an adequate supply of nectar for honeyeaters and *T. rostratus* is to be supplied throughout the year (Hopkins & Hnatiuk 1981).

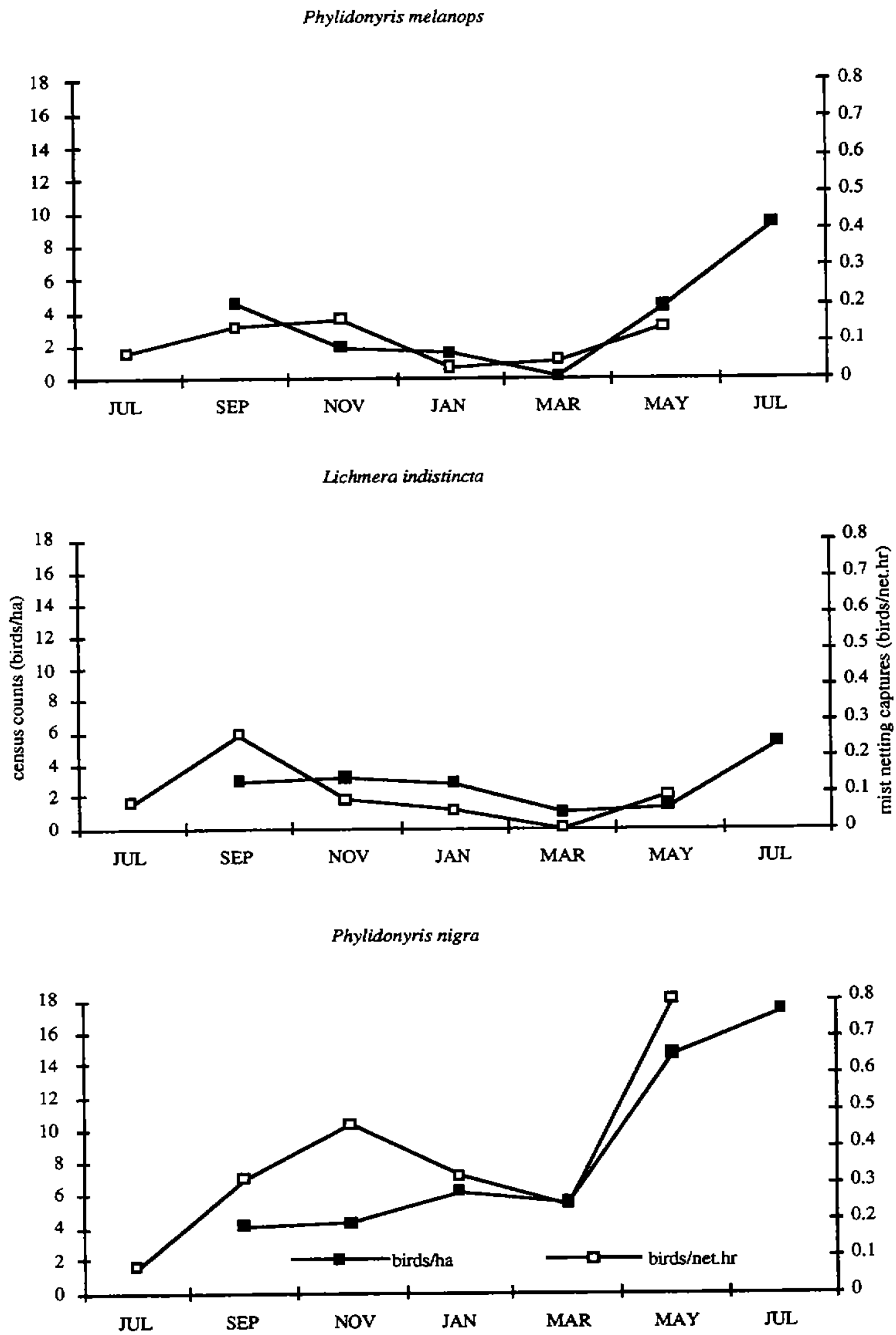

Figure 44: Overall abundance of *Phylidonyris melanops*, *P. nigra* and *Lichmera indistincta* during each survey month, as estimated from census counts and mist-netting.

Of the rehabilitated sites, Site 2 had very few flowering species, in part due to the relatively short time that had elapsed since rehabilitation began, whereas Site 3 had a large number of flowering species and large plants that produced numerous flowers per plant. Neither site had plant associations that closely resembled the three undisturbed sites studied, although the nectar-feeding animals they supported were similar to those at Site 1. For example, *P. melanops* was consistently most abundant at Sites 1 and 3. *T. rostratus* was trapped only at Sites 1, 2 and 3 in March, and at Sites 4 and 5 in July. These common trends at Sites 1, 2 and 3 were probably due to the close proximity of Sites 2 and 1, and the considerable diversity of flowering plants at Sites 1 and 3.

This study has confirmed the importance of establishing and maintaining high plant species diversity on rehabilitated land at Eneabba. Appropriate diversity could be achieved within particular sites by developing plant associations similar to that at Site 1, or by establishing a variety of plant associations at adjacent sites. Plant species worthy of inclusion in planting programs include: *A. cygnorum*, *C. sanguineus*, *E. tetragona*, *E. todtiana*, *B. attenuata*, *Calothamnus quadrifidus*, *Verticordia* species that flower from November to February, *Dryandra* sp. unid. and *Banksia* species that are particularly important to *T. rostratus*, and members of the Papilionaceae and Asteraceae that are normally considered to be pollinated by insects, but are also visited by honeyeaters and mammals.

5.4.4 Foraging activity by birds other than honeyeaters

The predominant foraging activities observed for birds other than honeyeaters at each site were influenced by the site's vegetation structure. For instance, the very dense canopy cover at Site 5 (144 $cm^2/100\ m^2$, Chapter 3) made it extremely difficult to ascertain whether ground foraging occurred. Although Site 4 had a very high plant density (317 plants/100 m^2), its lesser canopy cover (86.5 $cm^2/100\ m^2$) permitted observation of some ground foraging. In contrast, Site 1, which exhibited the highest frequency of ground foraging, had relatively low canopy cover (95.3 $cm^2/100\ m^2$) and plant density (147 plants/100 m^2). This site presumably provided birds with ample open ground on which to forage, yet nearby vegetation was able to supply adequate shelter. The rehabilitated Sites 2 and 3 had large areas of bare ground, with the canopy cover at Site 3 only 44 $cm^2/100m^2$, with the lack of shelter presumably leading to a reduced incidence of ground foraging.

The apparent predominance of aerial feeding over Sites 1, 2 and 5 may be related to the relatively low vegetation at these locations, and the consequent ease with which brief excursions above the canopy could be seen.

5.4.5 Food sources of mammals other than *Tarsipes rostratus*

Pseudomys albocinereus is a generalist granivore, feeding to a large extent on seeds and plant material, as well as insects (Dell & Chapman 1981; Morris & Bradshaw 1981). This species is considered to be well-adapted to extended dry seasons (four to seven months long) when little free water is available (Morris 1991). Nevertheless, *P. albocinereus* does not possess the same physiological attributes of other native rodent species that live in arid environments. Instead, it supplements its water intake during the summer months, when the water content of plants is relatively low, by increasing its arthropod consumption (Morris & Bradshaw 1981).

The present study has shown that insects were taken by *P. albocinereus* at Eneabba throughout the year, but was unable to determine whether the intake of insects varied between months. Nevertheless, the low incidence of insects in faecal smears in November 1987 may have reflected the availability of water in plants and on the soil surface caused by the relatively high rainfall (40 mm) received during that month .

Morris & Bradshaw (1981) have suggested that *Mesomelaena tetragona* (sedge), *Spinifex hirsutis*, *D. nivea*, *Conostylis aculeata*, *Daviesia juncea* and *Eremaea* sp are important food sources for *P. albocinereus* at Cockle Shell Gully and Watheroo National Park. Facial smears collected from *P. albocinereus* during the present study indicate that these animals foraged on at least 17 plant species at Eneabba (Appendix 8). Although pollen from genera other than sedges and grasses represented at Watheroo was present, counts of grains are unlikely to indicate the relative importance of different plant species. Plant material other than flowers could be eaten by *P. albocinereus*, in which case pollen would not appear in the smears. The importance of sedges as a source of food at Eneabba is unclear, although it may be significant that Site 4, which recorded the highest capture rates for *P. albocinereus*, had the highest densities of sedges (see Chapter 3).

Sminthopsis granulipes is a carnivorous marsupial, feeding opportunistically on arthropods such as spiders, centipedes, beetles, moths, termites, ants, sawflies, cockroaches, grasshoppers and flies (Chapman & Dell 1978). The stomach contents from a specimen collected during March in the wheatbelt by Chapman & Dell (1977) contained insects plus some seeds and flower parts. The diversity of pollen detected on *S. granulipes* in the present study may indicate that flowers such as *Verticordia* and *Beaufortia* were important sources of insects, especially beetles.

A study of insect abundance conducted at rehabilitated Sites 2 and 3 and undisturbed Sites 1 and 4 in January and March 1988 indicated that the two rehabilitated sites had significantly fewer insect species and a lower biomass than the undisturbed sites (Hoyle 1988) (Table 15). Differences were particularly noticeable in March, when insect numbers were seasonally low. Rehabilitated Site 2 had few beetles compared with other sites, although numerous ants were recorded in January. At Sites 1 and 4, most of the insects collected during sampling in January were beetles and spiders, whereas ants were predominant in March.

Table 15: Insect abundance and number of species collected during sweep-sampling in January and March 1988 (after Hoyle 1988).

Site	January		March	
	Number of specimens	Number of species	Number of specimens	Number of species
1	359	39	117	18
2	232	28	24	10
3	273	31	76	14
4	417	35	126	21

Spiders are considered to be important as a means of providing stability within terrestrial arthropod assemblages (Coyles 1989, in Nichols *et al.* 1989). Spider communities within rehabilitated areas previously mined for bauxite in the Jarrah forest, do not reach the complexity of unmined forest until at least eight years after rehabilitation has commenced (Nichols *et al.* 1989). Two factors that have been correlated with an increase in the number of spider species are percentage ground cover and leaf litter depth. Vegetation height also appears to be positively related to the number of spiders observed foraging among plants. The fact that Sites 2 and 3 at Eneabba had much lower densities of spiders and other arthropods than did undisturbed Sites 1 and 4 may be a major reason for the absence of species such as *S. granulipes* from rehabilitated sites (Hoyle 1988).

Mus musculus tends to be omnivorous, consuming relatively large amounts of seed, in addition to insects and other plant material (Fox & Pople 1984). Studies in North America have shown that *M. musculus* feeds on a more limited range of seed types than do native rodents (Caldwell 1964, in Fox & Pople 1984). It is not known whether similar restrictions apply in Australia, although if so they could limit the speed with which *M. musculus* is able to recolonise rehabilitated areas.

Evidence suggesting that *Rattus fuscipes* (Bush Rat) and marsupials such as *Antechinus stuartii* (Brown Antechinus) feed on the nectar of flowers has been obtained in recent years (Whelan & Goldingay 1986; Cheal 1987; Carron *et al.* 1990; Day 1993; Collins *et al.* 1994). It is not known whether *M. musculus, P. albocinereus* or *S. granulipes* harvest nectar in the field.

5.4.6 Diets of frogs and reptiles

Frogs and reptiles are predominantly insectivorous, with a few predatory species that feed on smaller reptiles and frogs, and occasionally mammals. Some reptiles such as *Tiliqua rugosa* also feed on flowers, fruit and seed (Table 16). Stability and consistency of the invertebrate fauna is very important to frogs and reptiles that rely on this for food. Since insect groups differ in their seasonal abundance, failure of a rehabilitated area to support a diverse range of species for even part of the year may mean that stable populations of reptiles are unlikely to be maintained. Low insect abundance similar to that recorded at Sites 2 and 3 in March 1988 (Hoyle 1988) may therefore have contributed to the scarcity of reptiles at the same sites during this study.

Although many reptile species feed on the same insect taxa, they often differ in terms of their foraging location (fossorial, terrestrial or arboreal), the time of day at which they feed (nocturnal or diurnal), the size of the prey they catch, and the manner in which they catch their prey (stalking, pouncing or sitting and waiting). Factors such as these will determine the species that co-occur, and their preferences for habitat types. They may also have contributed to the differences in distribution of dragon and skink species observed among the undisturbed sites (see Chapter 4).

5.4.7 Concluding remarks

A major factor limiting the capacity of native animals to colonise rehabilitated sites appears to be the nature of soils at these locations. Soils at the rehabilitated sites examined during this study were hard, had poor drainage and a structure with low porosity and friability, despite top soil replacement and mulching. Many vertebrates depend on the soil as a source of food or shelter, with soil fauna especially important in the diet of reptiles. Poor representation of reptiles at the rehabilitated sites may in part be due to the absence of an adequate soil fauna.

Soil can be considered as the foundation of a self-sustaining ecosystem, since it is the place where nutrient recycling occurs. Fertilisers are often used in the early stages of rehabilitation to provide nutrients that will encourage and support new growth.

Ultimately, however, the ecosystem being developed will provide its own nutrient supply through recycling. Soil fauna which assist with nutrient recycling include the fungi, bacteria, earthworms, millipedes, termites and springtails (Majer 1989c). In addition, the burrowing activity of soil fauna such as earthworms, termites, ants and beetles increase the soil's aeration, drainage and penetrability by roots. More research is required with regard to the importance of soil fauna at undisturbed and rehabilitated sites.

Table 16: Use of food items by frog and reptile species trapped at the Eneabba study sites, as determined by the examination of gut contents by other workers.

Vertebrate species	Stomach contents and general remarks	Source of information
Frogs		
Myobatrachus gouldii (Turtle Frog)	Termites, + a few insects (grasshopper, ants, diptera), rootlets and bark. Ants, some termites, + a few beetles, spiders and some plant parts.	Calaby 1956 Murray 1980
Heleioporus eyrei (Moaning Frog)	Ants, plant parts, spiders, earthworms, roaches, grasshoppers, larvae, beetles, and centipedes.	Murray 1980
Heleioporus albopunctatus (burrowing frog)	Earthworms, spiders, ants, roaches, beetles, bugs, crickets, larvae and plant material.	Murray 1980
Limnodynastes dorsalis (Banjo Frog)	Spiders, earthworms, plant parts, beetles, grasshoppers, larvae, ants, moths, vertebrates (incl. Myobatrachus gouldii), flies, insect eggs and centipedes.	Murray 1980
Pseudophyrne guentheri (Guenther's Toadlet)	Ants and small woodlouse.	Murray 1980
Reptiles		
Pogona minor (Bearded Dragon)	Several bugs, grasshopper, and several ants. A few bugs and a few ants. Several bugs and grasshopper. Beetles, plant parts (incl. Patersonia flowers), termites, grasshoppers, larvae, spiders, ants, bugs, flies, roaches, wasps and vertebrates.	Chapman and Dell 1980 Murray 1980
Ctenophorous maculatus (Spotted Dragon)	Spiders and ants	Chapman and Dell 1979
Tympanocryptis adelaidensis (small dragon)	Ants, beetles, plant parts, larvae, bugs, roaches, grasshoppers, flies, insect eggs and wasps.	Murray 1980
Ctenotus fallens (small skink)	Grasshoppers, plant parts (eg. flower buds, leaf pieces & seeds/berries of Leucopogon sp), beetles, spiders, bugs, centipedes, termites, roaches, larvae, pupae, vertebrates (incl. a small skink, Lerista sp. and legless lizard, Aclys sp.), ants and flies.	Murray 1980
Ctenotus schomburgkii (small skink)	Termites, spider, earwig. Insects of Apoisea, Isoptera and Coleoptera.	Chapman and Dell 1980 Chapman and Dell 1979
Tiliqua rugosa (Bobtail)	Mainly seeds. + drafon fly, grasshopper, beetles and bugs. Beetle, larva, snails, leaves and buds.	Chapman and Dell 1980 Murray 1980
Lialis burtonis (Burton's Snake-lizard)	Feeds on small lizards, especially skinks. Feeds on geckos (eg. Diplodactylus spp.) and dragons (eg. Ctenophorus isolepis).	Cogger 1979 Storr et al 1990
Diplodactylus spinigerus (Western Spiny-tailed Gecko)	Spiders, grasshoppers, moths, + some larvae, ants, beetles, insect eggs, woodlice, bugs, mosquitoes and plant parts.	Murray 1980
Rhinoplocephalus gouldii (Gould's Snake)	Feeds mainly on lizards.	Cogger 1979
Notechis curtis (Bardick)	Feeds on lizards, frogs, insects & small mammals.	Cogger 1979 Shine 1982

Other factors that affect the rate of succession in rehabilitated lands are the degree of isolation from undisturbed native vegetation and the relative abundance of opportunistic and specialist fauna (Majer 1989b). Undisturbed vegetation that is reasonably close to rehabilitated areas provides fauna that may colonise rehabilitated areas when they are suitable for occupation. Colonisation may only occur for part of the year, e.g. when opportunistic species are very mobile, or when rehabilitated areas have developed physical attributes approaching those of undisturbed habitats. Rehabilitated areas may take 30 years or more to mature to a stage where they are suitable for fauna species such as the frog *Myobatrachus gouldii* that have specific habitat requirements. In general, colonisation by animal species increases greatly as the structure of vegetation at rehabilitated locations approaches that of undisturbed sites. Further changes to the fauna at Sites 2 (five years old) and 3 (10 years old) are therefore to be anticipated.

The diversity of plants used in the rehabilitated sites at Eneabba is high, although not quite as great as at nearby undisturbed sites. By 1987-88, vegetation at the rehabilitated sites was able to support mobile and upper canopy feeders such as honeyeaters and *Diplodactylus spinigerus*. To a lesser extent, it also catered for *T. rostratus*, *P. albocinereus*, *Pogona minor* and *Ctenophorus maculatus* for part of the year. Pollination is likely to be effective at the rehabilitated sites in view of the presence of honeyeaters, thus providing an ingredient that is essential if a self-regenerating system involving plant species that rely on seeds is to be established. Although a large number of species in kwongan heaths can resprout after fire, many others are killed and are regenerated from seed (Pate *et al*. 1984). Ants that collect the elaeosomes from seeds may be an important part of the regeneration process, as they disperse and store intact seeds on the ground (Majer 1989c; Mossop 1989).

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8. Appendices

Appendix 1: Plant species densities at Sites 1, 2, 3, 4 and 5.

Site	Species	Density (plants//100m2)
1	*Acacia auronitens* LINDL.	1.11
	Acanthocarpus preissii LEHM.	1.25
	Actinostrobus acuminatus PARL.	1.00
	Alexgeorgea arenicola CARLQ.	1.50
	Allocasuarina humilis (OTTO & DIETR.)L.JOHNSON	1.00
	Allocasuarina microstachya (MIQ.)L.JOHNSON	1.28
	Amphipogon turbinatus R.BR.	2.24
	Astroloma microdonta F.MEULL. ex BENTH.	1.00
	Astroloma xerophyllum (DC.)SOND.	1.00
	Baeckea grandiflora BENTH.	1.00
	Banksia grossa A.S. GEORGE	1.00
	Beaufortia elegans SCHAU.	1.29
	Burchardia umbellata R.BR.	1.20
	Burtonia conferta DC.	1.00
	Calectasia cyanea R.BR.	1.00
	Calothamnus sanguineus LABILL.	1.00
	Calothamnus torulosus SCHAU.	1.00
	Calytrix superba C.GARDNER & A.S.GEORGE	2.40
	Calytrix tenuifolia (MEISN.)BENTH.	1.14
	Cassytha flava NEES	1.00
	Cassytha glabella R.BR.	1.05
	Caustis dioica R.BR.	1.18
	Comesperma calymega LABILL.	1.00
	Comesperma drummondii STEETZ.	1.00
	Conostylis aculeata R.BR.	1.28
	Conostylis androstemma F.MUELL.	1.67
	Constylis dielsii W.FITZG.	1.18
	Conostylis teretifolia J.W.GREEN	1.53
	Dampiera oligophylla BENTH. var. *ju* ...	1.73
	Dampiera spicigera BENTH.	1.98
	Darwinia neildiana F.MUELL	1.52
	Darwinia sanguinea (MEISN)BENTH.	1.22
	Darwinia speciosa (MEISN)BENTH.	1.00
	Daviesia daphnoides MEISN	1.00
	Daviesia divaricata BENTH.	1.00
	Daviesia juncea SM.	1.00
	Daviesia nudiflora MEISN.	1.00
	Daviesia pedunculata BENTH.	1.07
	Daviesia quadrilatera BENTH.	1.00
	Diplolaena ferruginea P.G.WILSON	1.00
	Drosera paleacea DC.	4.75
	Dryandra nivea (LABILL.)R.BR.	1.00
	Dryandra shuttleworthiana MEISN.	1.00
	Dryandra tridentata MEISN.	1.00
	Ecdeiocolea monostachya F.MUELL.	2.04
	Eremaea acutifolia F. MUELL.	1.00
	Eremaea beaufortioides BENTH.	1.28
	Eremaea violacea F.MUELL.	1.00
	Eucalyptus tetragona (R.BR.)F.MUELL.	1.00
	Gastrolobium pauciflorum C.GARDNER	1.00
	Geleznowia verrucosa TURCZ.	1.29

	Glischrocaryon aureum (LINDL.)ORCH.	2.33
	Gompholobium shuttleworthii MEISN.	1.00
	Goodenia caerulea R. BR.	3.74
	Grevillea shuttleworthiana MEISN.	1.00
	Hakea auriculata MEISN.	1.00
	Haeka candolleana MEISN.	1.00
	Hakea corymbosa R.BR.	1.00
	Hakea incrassata R.BR.	1.00
	Haemodorum aff. *paniculatum* LINDL.(EAG.1...	1.20
	Hemiandra pungens R.BR.	1.00
	Hibbertia crassifolia (TURCZ.)BENTH.	1.53
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	1.60
	Hibbertia huegelii (ENDL.)F.MUELL.	1.19
	Hybanthus floribundus (LINDL.)F.MUELL.	1.00
	Hypocalymma xanthopetalum F.MUELL.	1.00
	Isopogon tridens F.MUELL.	1.00
	Jacksonia floribunda ENDL.	1.05
	Lambertia multiflora LINDL.	1.00
	Lasiopetalum drummondii BENTH.	1.25
	Lepidobolus chaetocephalus F.MUELL.	1.64
	Lepidobolus tenue BENTH.	1.48
	Leptospermum erubescens SCHAU.	1.00
	Leptospermum spinescens ENDL.	1.00
	Leucopogon conostephioides DC.	1.00
	Leucopogon striatus R.BR. RJH771131	1.20
	Logania spermacocea F.MUELL.	3.17
	Lomandra hastilis (R.BR.)EWART	1.00
	Lomandra preissii (ENDL.)EWART	1.14
	Lyginia barbata R.BR.	1.29
	Melaleuca acerosa SCHAU.	1.19
	Melaleuca trichophylla LINDL.	1.18
	Mesomelaena stygia (R.BR.)NEES var ...	2.12
	Mesomelaena stygia (R.BR.)NEES var ...	1.00
	Mesomelaena tetragona (R.BR.)BENTH.	1.00
	MonotaxiS grandiflora ENDL.	1.00
	Neurachne alopecuroidea R.BR.	1.00
	Patersonia juncea LINDL.	1.00
	Persoonia acicularis F. MUELL.	1.00
	Petrophile brevifolia LINDL.	1.13
	Petrophile inconspicua MEISN.	1.00
	Petrophile macrostachya R.BR.	1.00
	Phymatocarpus porphyrocephalus F.MUELL.	1.14
	Pileanthus filifolius MEISN.	1.45
	Pimelea sulphurea MEISN.	1.00
	Restio sphacelatus R.BR.	2.45
	Scaevola canescens BENTH.	1.00
	Schoenus brevisetis (R.BR.)BENTH.	1.77
	Schoenus subbarbatus KUEK.	4.15
	Stachystemon axillaris A S.GEORGE	1.00
	Stylidium adpressum BENTH.	1.00
	Stylidium crossocephalum F.MUELL.	1.33
	Stylidium piliferum R.BR.	1.00
	Stylidium repens R.BR.	1.00
	Templetonia biloba (BENTH.)POLHILL	1.00
	Tetraria octandra (NEES)KUEK.	2.57
	Thysanotus sparteus R.BR.	1.00
	Thysanotus spiniger N.H. BRITTAN	1.00
	Tricoryne elatior R.BR.	1.00

	Tricoryne sp. (EAG 1541)	1.00
	Xanthorrhoea reflexa D.A.HERBERT	1.25
	Xanthosia huegelii (BENTH.)STEUD.	1.00
	not specified	1.00
2	*Acacia auronitens* LINDL.	1.25
	Acacia pulchella R.BR.	1.20
	Acanthocarpus preissii LEHM.	0.57
	Allocasuarina humilis (OTTO & DIETR.)L.JOHNSON	1.14
	Allocasuarina microstachya (MIQ.)L.JOHNSON	1.14
	Amphipogon turbinatus R.BR.	1.00
	Astroloma microdonta F. MUELL. ex BENTH.	1.57
	Astroloma xerophyllum (DC.)SOND.	1.71
	Banksia attenuata R.BR.	1.14
	Banksia candolleana MEISN.	1.00
	Banksia hookeriana MEISN.	1.00
	Banksia lanata A.S.GEORGE	1.00
	Beaufortia bracteosa DIELS	4.00
	Beaufortia elegans SCHAU.	1.76
	Calothamnus sanguineus LABILL.	1.20
	Calothamnus torulosus SCHAU.	1.50
	Caustis dioica R.BR.	1.48
	Caustis indet. 1	1.50
	Conospermum triplinervium R.BR.	1.51
	Conostylis aculeata R.BR.	1.80
	Conostylis dielsii W.FITZG.	1.75
	Conostylis neocymosa S.D.HOPPER	1.30
	Conostylis teretifolia J.W.GREEN	1.14
	Darwinia sanguinea (MEISN.)BENTH.	1.00
	Darwinia speciosa (MEISN.)BENTH.	1.00
	Daviesia divaricata BENTH.	1.14
	Daviesia juncea SM.	1.00
	Daviesia nudiflora MEISN.	1.20
	Daviesia quadrilatera BENTH.	0.80
	Dryandra carlinoides MEISN.	1.29
	Dryandra nivea (LABILL.)R.BR.	1.00
	Dryandra shuttleworthiana MEISN.	1.85
	Ecdeiocolea monostachya F.MUELL.	1.20
	Eremaea acutifolia F.MUELL.	1.00
	Eremaea beaufortioides BENTH.	1.71
	Eremaea violacea F.MUELL.	2.36
	Eucalyptus tetragona (R.BR.)F.MUELL.	1.25
	Eucalyptus todtiana F.MUELL.	1.00
	Gastrolobium pauciflorum C.GARDNER	1.25
	Geleznowia verrucosa TURCZ.	1.00
	Gompholobium tomentosum LABILL.	1.20
	Grevillea eriostachya LINDL.	1.00
	Hakea auriculata MEISN.	1.00
	Hakea brachyptera MEISN.	1.00
	Hakea candolleana MEISN.	1.00
	Hakea corymbosa R.BR.	1.14
	Hakea costata MEISN.	1.00
	Hakea incrassata R.BR.	1.25
	Hakea smilacifolia MEISN.	1.14
	Hibbertia crassifolia (TURCZ.)BENTH.	1.50
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	1.00
	Hybanthus floribundus (LINDL.)F.MUELL.	1.14
	Isopogon tridens F.MUELL.	2.40

	Jacksonia floribunda ENDL.	1.14
	Lambertia multiflora LINDL.	1.20
	Laxmania omnifertilis	1.00
	Laxmannia sessiliflora DCNE. ssp. *i* ...	1.26
	Lepidobolus chaetocephalus F.MUELL.	1.23
	Lepidosperma tenue BENTH.	1.45
	Leptospermum spinescens ENDL.	1.68
	Leucopogon conostephioides DC.	1.00
	Leucopogon hispidus E.PRITZ.	1.00
	Leucopogon leptanthus BENTH.	1.71
	Leucopogon striatus R.BR. RJH771131.	1.14
	Loxocarya fasciculata (R.BR.)BENTH.	1.14
	Lyginia barbata R.BR.	1.23
	Lysinema ciliatum R.BR.	1.00
	Melaleuca acerosa SCHAU.	2.45
	Melaleuca hamulosa TURCZ.	4.31
	Melaleuca holosericea SCHAUER	1.00
	Melaleuca trichophylla LINDL.	2.09
	Mesomelaena stygia (R.BR.)NEES var ...	1.39
	Mesomelaena stygia (R.BR.)NEES var ...	1.14
	Mesomelaena tetragona (R.BR.)BENTH.	1.20
	Mirbelia spinosa BENTH.	1.23
	Petrophile drummondii MEISN.	1.20
	Petrophile inconspicua MEISN.	1.00
	Petrophile media R.BR.	1.53
	Phymatocarpus porphyrocephalus F.MUELL.	1.40
	Restio sphacelatus R.BR.	1.00
	Scaevola canescens BENTH.	1.14
	Scaevola paludosa R.BR.	1.00
	Schoenus brevisetis (R.BR.)BENTH.	1.14
	Schoenus sp. 1 aff. *pleiostemoneus* F.MUELL.	0.57
	Schoenus sp. 1 aff. *pleiostemoneus* F.MUELL..	1.23
	Schoenus subbarbatus KUEK.	1.43
	Scholtzia capitata F.MUELL.ex BENTH.	1.00
	Sphaerolobium gracile BENTH.	1.14
	Stachystemon axillaris A.S.GEORGE	1.14
	Stylidium crossocephalum F.MUELL.	1.27
	Stylidium repens R.BR.	1.23
	Thysanotus teretifolius N.H.BRITTAN	2.00
	Thysanotus triandrus (LABILL.)R.BR.	1.00
	Verticordia grandiflora ENDL.	1.00
	Xanthorrhoea reflexa D.A.HERBERT	1.00
	Xylomelum angustifolium KIPP. & MEISN.	1.71
3	*Acacia pulchella* R.BR.	1.86
	Actinostrobus acuminatus PARL.	1.00
	Allocasuarina humilis (OTTO & DIETR.)L.JOHNSON	1.00
	Anigozanthos humilis LINDL.	1.00
	Astroloma microdonta F.MUELL. ex BENTH.	1.00
	Astroloma xerophyllum (DC.)SOND.	1.00
	Banksia attenuata R.BR.	1.00
	Banksai leptophylla A.S.GEORGE	1.00
	Beaufortia elegans SCHAU.	12.00
	Boronia ramosa (LINDL)BENTH. ssp. ...	1.00
	Calothamnus sanguineus LABILL.	2.00
	Comesperma calymega LABILL.	1.00
	Conostylis aculeata R.BR.	1.44
	Conostylis aurea LINDL.	1.00

	Conostylis dielsii W.FITZG.	1.67
	Conostylis neocymosa S.D.HOPPER	1.50
	Conothamnus trinervis LINDL.	1.00
	Daviesia nudiflora MEISN.	1.00
	Drosera paleacea DC.	5.22
	Dryandra nivea (LABILL.)R.BR.	2.00
	Dryandra tortifolia KIPP. ex R.BR.	1.00
	Eremaea beaufortioides BENTH.	1.38
	Eremaea violacea F.MUELL.	2.07
	Eucalyptus tetragona (R.BR.)F.MUELL.	1.00
	Hakea costata MEISN.	1.00
	Hibbertia acerosa (R.BR. ex DC.)BENTH.	1.00
	Hibbertia crassifolia (TURCZ.)BENTH.	1.00
	Hibbertia glaberrima	1.00
	Hibbertia aff. *furfuracea* (R.BR.ex DC.)BENTH.	1.00
	Isopogon adenanthoides MEISN.	1.14
	Isopogon tridens F.MUELL.	1.00
	Jacksonia floribunda ENDL.	1.00
	Lambertia multiflora LINDL.	1.00
	Laxmania omnifertilis	1.00
	Laxmannia sessilifora DCNE. ssp.*i* ...	1.00
	Lechenaultia stenosepala E.PRITZ.	8.00
	Lepidosperma tenue	1.00
	Leptospermum spinescens ENDL.	1.00
	Lyginia barbata R.BR.	1.00
	Melaleuca acerosa SCHAU.	4.87
	Melaleuca scabra R.BR.	1.00
	Mesomelaena stygia (R.BR.)NEES var ...	1.13
	Mesomelaena tetragona (R.BR.)BENTH.	1.00
	Patersonia juncea LINDL.	1.00
	Petrophile brevifolia LINDL.	1.29
	Petrophile drummondii MEISN.	1.43
	Petrophile macrostachya R.BR.	1.50
	Phymatocarpus porphyrocephalus F.MUELL.	1.00
	Schoenus brevisetis (R.BR.) BENTH.	1.00
	Schoenus unispiculatus F.MUELL.	1.00
	Scholtzia laxiflora BENTH.	1.00
	Xanthosia huegelii (BENTH.)STEUD.	1.00
4	*Acacia auronitens* LINDL.	1.82
	Acanthocarpus preissii LEHM.	1.82
	Actinostrobus acuminatus PARL.	1.68
	Alexgeorgea arenicola CARLQ.	2.65
	Amphipogon turbinatus R.BR.	2.04
	Andersonia heterophylla SOND.	1.41
	Anigozanthos humilis LINDL.	1.82
	Arnocrinum preissii LEHM.	1.82
	Astroloma ? serratifolium (DC.)DRUCE.	1.55
	Banksia attenuata R.BR.	1.82
	Banksia candolleana MEISN.	9.45
	Banksia grossa A.S.GEORGE	31.95
	Banksia hookeriana MEISN.	42.18
	Beaufortia elegans SCHAU.	13.89
	Boronia ramosa (LINDL)BENTH. ssp. ...	1.82
	Burchardia umbellata R.BR.	1.82
	Calothamnus sanguineus LABILL.	1.82
	Calytrix empetroides (SCHAU.)BENTH.	2.28
	Cassytha flava NEES	1.82

	Cassytha pomiformis NEES	1.82
	Conostephium preissii SOND.	1.82
	Conostylis aurea LINDL.	2.27
	Conostylis dielsii W.FITZG.	1.65
	Conostylis neocymosa S.D. HOPPER	3.01
	Dampiera oligophylla BENTH. var. *ju* ...	1.69
	Dampiera spicigera BENTH.	2.42
	Darwinia neildiana F.MUELL.	1.82
	Darwinia speciosa (MEISN.)BENTH.	1.82
	Daviesia divaricata BENTH.	6.19
	Daviesia juncea SM.	1.82
	Daviesia nudiflora MEISN.	1.82
	Drosera paleacea DC.	1.82
	Dryandra tridentata MEISN.	1.82
	Ecdeiocolea monostachya F.MUELL.	3.57
	Eremaea acutifolia F.MUELL.	1.60
	Eremaea beaufortioides BENTH.	3.24
	Eremaea violacea F.MUELL.	3.70
	Eucalpytus todtiana F.MUELL.	3.64
	Goodenia caerulea R.BR.	2.73
	Hakea corymbosa R.BR.	10.91
	Hakea costata MEISN.	1.00
	Hemiandra pungens R.BR.	1.82
	Hibbertia crassifolia (TURCZ.)BENTH.	2.52
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	2.12
	Hypocalymma xanthopetalum F.MUELL.	2.45
	Jacksonia floribunda ENDL.	4.65
	Lachnostachys eriobotrya (F.MUELL.)DRUCE.	1.82
	Lepidobolus chaetocephalus F.MUELL.	4.11
	Lepidosperma tenue BENTH.	2.40
	Leptospermum spinescens ENDL.	3.55
	Leucopogon conostephioides DC.	1.82
	Leucopogon sp. 1	1.82
	Leucopogon striatus R.BR.RJH771131.	1.82
	Lomandra hastilis (R.BR.)EWART	3.66
	Lomandra preissii (ENDL.)EWART	1.82
	Lyginia barbata R.BR.	4.09
	Melaleuca acerosa SCHAU.	4.64
	Mesomelaena stygia (R.BR.)NEES var ...	2.98
	Mesomelaena stygia (R.BR.)NEES var ...	2.73
	Monotaxis grandiflora ENDL.	1.82
	Persoonia acicularis F.MUELL.	2.22
	Petrophile brevifolia LINDL.	1.69
	Petrophile drummondii MEISN.	4.04
	Petrophile macrostachya R.BR.	1.82
	Pileanthus filifolius MEISN.	2.75
	Pimelea angustifolia R.BR.	2.73
	Pityrodia hemigenioides (F.MUELL.)BENTH.	7.48
	Resitio sphacelatus R.BR.	6.30
	Schoenus brevisetis (R.BR.)BENTH.	1.35
	Schoenus curvifolius (R.BR.)BENTH.	3.14
	Schoenus pedicellatus (R.BR.)BENTH.	1.82
	Schoenus subbarbatus KUEK.	4.17
	Scholtzia laxiflora BENTH.	5.03
	Stirlingia latifolia (R.BR.)STEUD.	9.65
	Stylidium adpressum BENTH.	1.82
	Stylidium crossocephalum F.MUELL.	1.84

	Stylidium repens R.BR.	2.52
	Thysanotus sp. 1	1.82
	Thysanotus sparteus R.BR.	1.82
	Tricoryne sp. (EAG 1541)	1.82
	Verticordia densiflora LINDL.	3.31
	Xanthosia huegelii (BENTH.)STEUD.	1.00
	Xylomelum angustifolium KIPP. & MEISN.	121.86
	not specified	5.09
5	*Acacia pulchella* R.BR.	1.00
	Actimostrobus acuminatus PARL.	1.00
	Alexgeorgea arenicola CARLQ.	1.25
	Amphipogon turbinatus R.BR.	1.33
	Andersonia heterophylla SOND.	1.00
	Arnocrinum preissii LEHM.	1.00
	Astroloma xerophyllum (DC.)SOND.	1.00
	Banksia candolleana MEISN.	1.00
	Banksia grossa A.S.GEORGE	1.00
	Banksia lanata A.S.GEORGE	1.00
	Beaufortia elegans SCHAU.	6.13
	Burchardia umbellata R.BR.	1.00
	Caladenia flava R.BR.	4.46
	Calothamnus sanguineus LABILL	1.00
	Calothamnus cf. villosus R.BR.	1.88
	Calytrix empetroides (SCHAU.)BENTH	1.00
	Cassytha flava NEES	1.00
	Cassytha glabella R.BR.	1.00
	Cassytha pomiformis NEES	1.00
	Conostephium preissii SOND.	1.00
	Conostylis aculeata R.BR.	1.00
	Conostylis dielsii W.FITZG.	1.17
	Conostylis neocymosa S.D.HOPPER	1.63
	Darwinia neildiana F.MUELL.	1.00
	Daviesia divaricata BENTH.	1.00
	Drosera paleacea DC.	2.00
	Dryandra shuttleworthiana MEISN.	1.00
	Dryandra tortifolia KIPP. ex R.BR.	1.00
	Dryandra tridentata MEISN.	1.00
	Eremaea acutifolia F.MUELL.	1.00
	Eremaea beaufortioides BENTH.	1.30
	Eremaea violacea F.MUELL.	1.00
	Hakea corymbosa R.BR.	1.00
	Hakea costata MEISN.	1.33
	Hakea obliqua R.BR.	1.00
	Hakea trifurcata (SM.)R.BR.	1.00
	Haemodorum aff. *paniculatum* LINDL. (EAG.1 ...	1.00
	Hibbertia crassifolia (TURCZ.)BENTH.	1.00
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	1.07
	Jacksonia floribunda ENDL.	1.00
	Johnsonia pubescens LINDL.	1.33
	Laxmannia sessiliflora DCNE. ssp. *i* ...	1.17
	Lepidobolus chaetocephalus F.MUELL.	1.83
	Lepidosperma tenue BENTH.	1.00
	Leucopogon hispidus E.PRITZ.	1.00
	Loxocarya cinerea R.BR.	1.00
	Lyginia barbata R.BR.	1.00
	Melaleuca acerosa SCHAU.	1.68
	Mesomelaena stygia (R.BR.)NEES var ...	1.67
	Mesomelaena stygia (R.BR.)NEES var ...	3.50

	Mirbelia spinosa BENTH.	1.00
	Neurachne alopecuroidea R.BR.	1.00
	Petrophile brevifolia LINDL.	1.50
	Petrophile drummondii MEISN.	1.27
	Petrophile ericifolia R.BR.	1.00
	Phymatocarpus porphyrocephalus F.MUELL.	1.00
	Pileanthus filifolius MEISN.	1.23
	Pimelea angustifolia R.BR.	1.00
	Restio sphacelatus R.BR.	1.33
	Schoenus brevisetis (R.BR.) BENTH	2.00
	Schoenus subbarbatus KUEK.	2.38
	Scholtzia laxiflora BENTH.	1.25
	Stylidium crossocephalum F. MUELL.	1.00
	Stylidium dichotomum DC.	1.67
	Stylidium repens R.BR.	1.00
	Verticordia densiflora LINDL.	1.86
	Verticordia aff. *nitens* (LINDL.)SCHAU.	1.25
	Xylomelum angustifolium KIPP. & MEISN.	1.00

Appendix 2: Plant species cover at Sites 1, 3, 4 and 5 (no data available for Site 2).

Site	Species	Cover (cm^2/m)
1	*Acacia auronitens* LINDL	0.73
	Acanthocarpus preissii LEHM.	0.15
	Actinostrobus acuminatus PARL.	1.85
	Alexgeorgea arenicola CARLQ.	0.20
	Allocasuarina humilis (OTTO & DIETR.)L.JOHNSON	10.05
	Allocasuarina microstachya (MIQ.)L.JOHNSON	2.65
	Amphipogon turbinatus R.BR.	1.50
	Astroloma microdonta F.MUELL. ex BENTH.	0.90
	Banksia grossa A.S.GEORGE	4.63
	Beaufortia elegans SCHAU.	0.73
	Burtonia conferta DC.	0.15
	Calectasia cyanea R.BR.	0.15
	Calothamnus sanguineus LABILL.	1.80
	Calothamnus torulosus SCHAU.	0.90
	Calytrix tenuifolia (MEISN.)BENTH.	0.60
	Cassytha glabella R.BR.	0.18
	Caustis dioica R.BR.	1.85
	Conostylis aculeata R.BR.	0.15
	Conostylis androstemma (LINDL.)F.MUELL.	0.30
	Conostylis dielsii W.FITZG.	0.05
	Conostylis teretifolia J.W. GREEN	0.20
	Dampiera oligophylla BENTH. var. *ju* ...	0.37
	Dampiera spicigera BENTH.	0.45
	Darwinia neildiana F. MUELL.	0.87
	Darwinia sanguinea (MEISN.)BENTH.	0.55
	Darwinia speciosa (MEISN.)BENTH.	0.10
	Daviesia divaricata BENTH.	2.90
	Daviesia juncea SM.	0.60
	Daviesia nudiflora MEISN.	0.47
	Daviesia pedunculata BENTH.	0.32
	Dryandra shuttleworthiana MEISN.	3.01
	Ecdeiocolea monostachya F.MUELL.	5.82
	Eremaea acutifolia F.MUELL.	1.35
	Eremaea beaufortioides BENTH.	2.35
	Eremaea violacea F.MUELL.	1.69
	Eucalyptus tetragona (R.BR.)F.MUELL.	0.75
	Gastrolobium pauciflorum C.GARDNER	0.05
	Geleznowia verrucosa TURCZ.	0.43
	Glischrocaryon aureum (LINDL.)ORCH.	0.05
	Goodenia caerulea R.BR.	0.43
	Grevillea shuttleworthiana MEISN.	0.10
	Hakea auriculata MEISN.	0.65
	Hakea candolleana MEISN.	2.38
	Hakea corymbosa R.BR.	1.35
	Hakea incrassata R.BR.	0.70
	Hemiandra pungens R.BR.	0.60
	Hibbertia crassifolia (TURCZ.)BENTH.	1.21
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	2.15
	Hibbertia huegelii (ENDL.)F.MUELL.	0.93
	Hybanthus floribundus (LINDL.)F.MUELL.	0.35
	Hypocalymma xanthopetalum F.MUELL.	0.85
	Isopogon tridens F.MUELL.	2.10
	Jacksonia floribunda ENDL.	3.16
	Lambertia multiflora LINDL.	1.00

	Lasiopetalum drummondii BENTH.	0.33
	Lepidobolus chaetocephalus F.MUELL.	1.85
	Leptospermum spinescens ENDL.	0.30
	Leucopogon conostephioides DC.	0.10
	Logania spermacocea F.MUELL.	0.55
	Lomandra hastilis (R.BR.)EWART	0.55
	Lyginia barbata R.BR.	0.56
	Melaleuca acerosa SCHAU.	1.81
	Melaleuca trichophylla LINDL.	0.20
	Mesomelaena stygia (R.BR.)NEES var. ...	1.85
	Mesomelaena tetragona (R.BR.)BENTH.	0.80
	Monotaxis grandiflora ENDL.	0.30
	Persoonia acicularis F.MUELL.	0.20
	Petrophile brevifolia LINDL.	0.48
	Phymatocarpus porphyrocephalus F.MUELL.	1.85
	Pileanthus filifolius MEISN.	1.74
	Pimelea sulphurea MEISN.	0.13
	Restio sphacelatus R.BR.	4.52
	Scaevola canescens BENTH.	0.10
	Schoenus brevisetis (R.BR.)BENTH.	0.56
	Schoenus subbarbatus KUEK.	1.76
	Stylidium adpressum BENTH.	0.10
	Stylidium repens R.BR.	0.05
	Tetraria octandra (NEES)KUEK.	2.30
	Xanthorrhoea reflexa D.A.HERBERT	2.54
3	*Acacia pulchella* R.BR.	0.35
	Banksia attenuata R.BR.	1.90
	Banksia leptophylla A.S.GEORGE	8.00
	Beaufortia elegans SCHAU.	2.75
	Conostylis aculeata R.BR.	0.10
	Conostylis dielsii W.FITZG.	0.65
	Dryandra tortifolia KIPP. ex R.BR.	1.45
	Eremaea violacea F.MUELL.	0.25
	Hakea costata MEISN.	4.90
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	2.25
	Isopogon adenanthoides MEISN.	6.55
	Lambertia multiflora LINDL.	2.50
	Laxmannia sessiliflora DCNE. SSP. *i* ...	0.25
	Melaleuca acerosa SCHAU.	2.30
	Melaleuca scabra R.BR.	0.10
	Mesomelaena stygia (R.BR.)NEES var. ...	0.53
	Mesomelaena tetragona (R.BR.)BENTH.	2.60
	Patersonia juncea LINDL.	0.20
	Petrophile brevifolia LINDL.	0.77
	Petrophile drummondii MEISN.	2.32
	Schoenus brevisetis (R.BR.)BENTH.	2.70
	Scholtzia laxiflora BENTH.	0.60
4	*Acacia auronitens* LINDL.	0.30
	Acanthocarpus preissii LEHM.	0.10
	Actinostrobus acuminatus PARL.	5.74
	Alexgeorgea arenicola CARLQ.	0.35
	Amphipogon turbinatus R.BR.	0.43
	Andersonia heterophylla SOND.	0.39
	Baeckea grandiflora BENTH.	0.75
	Banksia attenuata R.BR.	2.60
	Banksia candolleana MEISN.	7.60
	Basnksia grossa A.S.GEORGE	7.00

	Banksia hookeriana MEISN.	3.25
	Banksia leptophylla A.S.GEORGE	3.15
	Beaufortia elegans SCHAU.	1.66
	Burchardia umbellata R.BR.	0.05
	Calothamnus sanguineus LABILL	0.85
	Calytrix empetroides (SCHAU.)BENTH.	0.21
	Cassytha flava NEES	0.67
	Cassytha pomiformis NEES	0.30
	Conostephium preissii SOND.	2.45
	Conostylis aurea LINDL.	0.20
	Conostylis dielsii W.FITZG.	0.15
	Conostylis neocymosa S.D.HOPPER	1.19
	Dampiera oligophylla BENTH. var. *ju* ...	0.15
	Dampiera spicigera BENTH.	0.10
	Darwinia neildiana F.MUELL.	0.25
	Darwinia speciosa (MEISN.)BENTH.	0.05
	Daviesia divaricata BENTH.	0.61
	Daviesia juncea SM.	0.59
	Daviesia nudiflora MEISN.	0.35
	Ecdeiocolea monostachya F.MUELL.	0.99
	Eremaea acutifolia F.MUELL.	1.59
	Eremaea beaufortioides BENTH.	1.88
	Eremaea violacea F.MUELL.	0.68
	Eucalyptus todtiana F.MUELL.	4.25
	Goodenia caerulea R.BR.	0.12
	Hakea corymbosa R.BR.	1.23
	Hakea costata MEISN.	0.05
	Hibbertia crassifolia (TURCZ.)BENTH.	0.69
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	0.80
	Hypocalymma xanthopetalum F.MUELL.	0.15
	Jacksonia floribunda ENDL.	1.33
	Johnsonia pubescens LINDL.	0.05
	Lachnostachys eriobotrya (F.MUELL.)DRUCE.	1.90
	Lepidobolus chaetocephalus F.MUELL.	1.69
	Lepidosperma tenue BENTH.	0.23
	Leptospermum spinescens ENDL.	0.33
	Leucopogon conostephioides DC.	0.20
	Leucopogon striatus R.BR.RJH771131.	0.17
	Lomandra hastilis (R.BR.)EWART	0.20
	Lomandra preissii (ENDL.)EWART	0.05
	Lyginia barbata R.BR.	0.30
	Melaleuca acerosa SCHAU.	1.75
	Mesomelaena stygia (R.BR.)NEES var. ...	0.38
	Persoonia acicularis F.MUELL.	0.05
	Phymatocarpus porphyrocephalus F.MUELL.	2.05
	Pileanthus filifolius MEISN.	0.59
	Pimelea angustifolia R.BR.	0.08
	Pityrodia bartlingii (LEHM.)BENTH.	0.05
	Pityrodia hemigenioides (F.MUELL.)BENTH.	0.46
	Platysace juncea (BUNGE)NORMAN	0.05
	Restio sphacelatus R.BR.	0.84
	Schoenus brevisetis (R.BR.)BENTH.	0.12
	Schoenus curvifolius (R.BR.)BENTH	0.13
	Schoenus pedicellatus (R.BR.)BENTH.	0.30
	Schoenus subbarbatus KUEK.	0.64
	Scholtzia laxiflora BENTH.	6.99
	Stirlingia latifolia (R.BR.)STEUD.	1.20
	Stylidium adpressum BENTH.	0.25

	Stylidium crossocephalum F.MUELL.	0.26
	Stylidium repens R.BR.	0.20
	Thysanotus sparteus R.BR.	0.08
	Tricoryne sp. (EAG 1541)	0.25
	Verticordia densiflora LINDL.	0.33
	Verticordia ovalifolia MEISN.	0.05
	Xylomelum angustifolium KIPP. & MEISN.	8.47
	not specified	0.58
5	*Actinostrobus acuminatus* PARL.	0.65
	Andersonia heterophylla SOND.	0.30
	Astroloma xerophyllum (DC.)SOND.	0.48
	Banksia candolleana MEISN.	1.05
	Banksia grossa A.S.GEORGE	1.40
	Banksia lanata A.S.GEORGE	12.08
	Beaufortia elegans SCHAU.	3.73
	Burchardia umbellata R.BR.	0.05
	Caladenia flava R.BR.	15.60
	Calothamnus sanguineus LABILL.	2.38
	Calothamnus cf. *villosus* R.BR.	22.30
	Calytrix empetroides (SCHAU.)BENTH.	0.25
	Cassytha flava NEES	7.63
	Cassytha pomiformis NEES	1.40
	Conostephium preissii SOND.	0.20
	Conostylis aculeata R.BR.	0.50
	Conostylis dielsii W.FITZG.	0.10
	Conostylis neocymosa S.D.HOPPER	1.38
	Daviesia divaricata BENTH.	0.20
	Daviesia nudiflora MEISN.	0.70
	Dryandra nivea (LABILL.)R.BR.	1.10
	Dryandra shuttleworthiana MEISN.	1.97
	Dryandra tridentata MEISN.	0.20
	Eremaea acutifolia F.MUELL.	0.15
	Eremaea beaufortioides BENTH.	4.15
	Eremaea violacea F.MUELL.	1.06
	Hakea corymbosa R.BR.	1.18
	Hakea costata MEISN.	1.18
	Hakea obliqua R.BR.	4.55
	Hibbertia crassifolia (TURCZ.)BENTH.	0.25
	Hibbertia aff. *furfuracea* (R.BR. ex DC.)BENTH.	1.53
	Jacksonia floribunda ENDL.	2.00
	Lepidobolus chaetocephalus F.MUELL.	1.63
	Melaleuca acerosa SCHAU.	2.54
	Mesomelaena stygia (R.BR.)NEES var. ...	0.74
	Mesomelaena stygia (R.BR.)NEES var. ...	0.60
	Petrophile drummondii MEISN.	1.00
	Phymatocarpus porphyrocephalus F.MUELL.	5.50
	Pileanthus filifolius MEISN.	0.15
	Restio sphacelatus R.BR.	1.22
	Schoenus curvifolius (R.BR.)BENTH.	0.35
	Schoenus subbarbatus KUEK.	0.20
	Scholtzia laxiflora BENTH.	6.65
	Verticordia densiflora LINDL.	22.90
	Verticordia aff nitens (LINDL.)SCHAU.	0.45
	Xylomelum angustifolium KIPP. & MEISN.	8.75

Appendix 3. Numbers of animals trapped in pitfalls and box traps at each site.

Animal species	July '87					September '87					November '87					January '88				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Frogs																				
N. pelobatoides	5	3	8	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H. albopunctatus	1	0	1	3	0	1	0	0	0	2	0	0	0	0	2	0	0	0	0	0
H. eyrei	2	0	0	0	1	1	0	0	0	2	0	0	0	0	4	0	0	0	0	0
P. guentheri	0	0	2	0	5	0	0	0	1	11	0	0	0	2	0	0	0	0	0	0
L. dorsalis	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M. gouldii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total no. frogs	**8**	**3**	**12**	**12**	**10**	**2**	**0**	**0**	**1**	**15**	**0**	**0**	**0**	**2**	**6**	**0**	**0**	**0**	**0**	**0**
Reptiles																				
C. fallens	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	2	0	0	5	0
C. pantherinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
C. schomburgkii	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	1	2
L. praepedita	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. rugosa	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
C. maculatus	0	0	0	0	0	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0
P. minor	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0
T. adelaidensis	0	0	0	0	0	0	0	0	1	0	0	0	0	5	4	0	0	0	4	1
D. spinigerus	0	0	0	0	0	3	3	2	2	1	3	3	3	3	0	0	1	2	1	1
Gecko sp	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
L. burtonis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
N. curtis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. gouldii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
V. littoralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total no. reptiles	**1**	**0**	**0**	**0**	**0**	**6**	**3**	**3**	**3**	**3**	**6**	**3**	**5**	**13**	**7**	**4**	**1**	**3**	**11**	**4**
Mammals																				
M. musculus	6	3	1	3	3	0	2	0	4	8	7	7	7	5	10	5	12	4	1	3
P. albocinereus	0	0	0	10	0	2	0	0	6	4	5	1	1	5	1	1	0	0	4	2
S. granulipes	3	0	0	1	0	0	0	0	1	0	8	0	0	2	1	3	0	0	1	0
T. rostratus	0	0	0	2	4	0	0	0	6	0	1	0	1	10	5	7	3	3	6	3
Total no. mammals	**9**	**3**	**1**	**16**	**7**	**2**	**2**	**0**	**17**	**12**	**21**	**8**	**9**	**22**	**17**	**16**	**15**	**7**	**12**	**8**

Animal species	March '88					May '88					July '88					September '88				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Frogs																				
N. pelobatoides	0	0	0	0	0	4	2	5	9	12	2	2	1	7	2	1	0	2	0	0
H. albopunctatus	0	0	0	0	2	2	3	1	0	3	0	0	1	0	0	0	0	0	1	0
H. eyrei	0	0	0	0	3	1	0	1	7	8	0	0	0	1	0	0	0	0	7	21
P. guentheri	0	0	0	0	0	2	1	0	3	10	0	1	3	0	6	0	0	1	4	18
L. dorsalis	0	0	0	0	0	1	2	0	0	0	0	0	0	0	1	0	0	0	0	0
M. gouldii	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total no. frogs	**0**	**0**	**0**	**0**	**5**	**11**	**8**	**7**	**19**	**33**	**2**	**3**	**5**	**8**	**9**	**1**	**0**	**3**	**12**	**40**
Reptiles																				
C. fallens	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C. pantherinus	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C. schomburgkii	0	0	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
L. praepedita	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. rugosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
C. maculatus	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. minor	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
T. adelaidensis	0	0	0	3	3	0	0	0	2	1	0	0	0	0	0	0	0	0	4	0
D. spinigerus	0	1	1	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0
Gecko sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L. burtonis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N. curtis	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. gouldii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V. littoralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total no. reptiles	**4**	**2**	**3**	**9**	**11**	**0**	**0**	**2**	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**3**	**1**	**0**	**5**	**0**
Mammals																				
M. musculus	7	5	2	2	2	7	4	2	4	7	5	0	3	3	4	2	1	1	1	8
P. albocinereus	2	0	0	1	0	1	0	0	4	0	0	0	0	2	2	0	0	0	2	0
S. granulipes	3	0	0	1	0	0	0	0	2	2	1	0	0	1	0	0	0	0	0	0
T. rostratus	5	2	7	0	0	2	0	0	1	0	0	0	0	2	3	1	0	0	3	4
Total no. mammals	**17**	**7**	**9**	**4**	**2**	**10**	**4**	**2**	**11**	**9**	**6**	**0**	**3**	**8**	**9**	**3**	**1**	**1**	**6**	**12**

N.B. Box traps and large pitfalls not used in July and September 1987; traps open for three nights rather than seven in July and September 1988.

Appendix 4. Total head length, mass and wing length measurements used to identify juvenile *Phylidonyris nigra* (White-cheeked Honeyeater).

Month of the year	Total head length (mm)	Mass (g)	Wing length (mm)	Likely juvenile	Trapping site
females Jan.	42.0	13.5	68		
	41.4	16.5	73		
	41.0	15.5	70		
	40.7	13.5	68		
	42.9	16.5	74		
	41.3	15.0	71		
	41.9	15.0	71		
	41.0	15.5	70		
females March	41.3	16.5	72		
	41.0	15.0	70		
	42.9	17.0	70		
	40.8	14.0	72		
females May	40.5	14.5	72		
	42.0	14.0	71		
	42.1	17.0	73		
	41.2	15.0	72		
	42.9	17.5	77		
	42.2	14.5	70		
	42.0	16.0	73		
	41.5	14.5	71		
	40.4	13.5	68		
	41.3	15.0	71		
	40.6	15.5	70		
	40.7	15.0	70		
	40.3	17.0	70		
	40.1	15.5	69		
	42.5	15.5	68		
females July	41.8	14.5	66	yes	3
females Sep.	42.1	16.0	73		
	41.9	17.5	71		
	41.7	14.0	78		
	41.3	15.0	71		
	42.0	17.0	68		
females Nov.	39.3	14.0	66	yes	3
	41 1	14.5	65	yes	5
	42.3	15 5	67		
males Jan.	45.3	19.0	76		
	45.9	18.5	77		
	44.8	17.5	75		
	45.7	18.5	75		

Appendix 4 (cont.). Total head length, mass and wing length measurements used to identify juvenile *Phylidonyris nigra* (White-cheeked Honeyeater).

Month of the year	Total head length (mm)	Mass (g)	Wing length (mm)	Likely juvenile	Trapping site
males March	45.5	20.0	74		
	45.3	19.5	79		
	45.2	20.5	79		
	44.9	18.5	76		
	45.6	18.5	76		
males May	45.9	19.0	77		
	43.0	16.5	72	perhaps	1
	44.0	18.5	77		
	45.5	20.0	78		
	45.5	18.5	76		
	44.6	18.5	77		
	43.5	17.5	74		
	43.9	19.5	76		
	45.0	19.0	76		
	44.5	18.5	75		
	46.3	17.5	75		
	45.4	19.5	77		
	44.6	19.5	76		
	45.5	19.5	78		
	43.5	18.0	75		
	45.4	19.5	76		
	44.6	19.0	76		
	43.9	18.0	77		
	45.5	18.0	75		
males July	45.3	16.5	76		
males Sep.	44.4	18.5	72	yes	3
	45.8	18.0	71	yes	3
	45.3	19.5	72	yes	3
	44.8	18.0	71	yes	3
	45.5	19.5	76		
males Nov.	43.4	17.0	71	yes	3
	46.4	20.5	73		
	43.6	17.5	73		
	45.0	20.5	75		
	44.1	19.0	73		
	45.7	18.5	72	yes	3
	45.0	18.0	74		
	45.2	18.0	75		
	43.9	18.0	75		
	45.1	21.5	79		
	45.1	20.0	77		
	45.2	17.0	73		

Appendix 5. Grain counts and percentages (bold) of pollen types carried by honeyeaters.

Pollen of plant species carried each month.	Site 1		Site 2		Site 3		Site 4		Site 5	
	grains	%	grains	%	grains	%	grains	%	grains	%
Jul-87										
Adenanthos cygnorum	14	**93.3**								
Dryandra nivea					19	**6.6**				
Lambertia multiflora			47	**18.7**						
Calothamnus sanguineus			192	**76.5**	252	**87.8**				
Total grains counted	15		251		287					
Sep-87										
Adenanthos cygnorum	26	**19.6**			242	**40.3**	78	**45.1**	52	**23.2**
Banksia hookeriana							40	**23.1**		
Dryandra falcata	32	**24.1**			22	**3.7**				
Lambertia multiflora					36	**6.0**				
Calothamnus quadrifidus	36	**27.1**			111	**18.5**	28	**16.2**	42	**18.8**
Calothamnus sanguineus					109	**18.1**			125	**55.8**
Eucalyptus macrocarpa					20	**3.3**				
Melaleuca trichophylla							15	**8.7**		
Total grains counted	133				601		173		224	
Nov-87										
Adenanthos cygnorum	248	**45.5**	216	**16.7**	537	**64.9**			888	**82.3**
Dryandra falcata			37	**2.9**						
Grevillea eriostachya							108	**26.2**	69	**6.4**
Beaufortia elegans							15	**3.6**		
Calothamnus quadrifidus	249	**45.7**	1019	**78.7**	43	**5.2**				
Calothamnus villosus							36	**8.7**	93	**8.6**
Eucalyptus macrocarpa					246	**29.7**				
Verticordia densiflora							12	**2.9**		
Verticordia grandis							15	**3.6**	16	**1.5**
Total grains counted	545		1294		828		413		1079	
Jan-88										
Adenanthos cygnorum	1217	**98.7**			1705	**99.7**	541	**88.7**	716	**89.8**
Eucalyptus todtiana									52	**6.5**
Melaleuca trichophylla							12	**20.0**		
Total grains counted	1233				1710		610		797	
Mar-88										
Adenanthos cygnorum					1621	**90.1**	347	**76.7**		
Banksia leptophylla					125	**6.9**	53	**11.7**		
Banksia menzeissi							14	**3.1**		
Dryandra sp. unid.							12	**2.6**		
Myrtaceae sp. L					20	**1.1**	20	**4.4**		
Total grains counted					1800		452			
May-88										
Adenanthoc cygnorum	40	**3.3**								
Banksia hookeriana	112	**9.3**	184	**8.4**	96	**2.8**	113	**50.2**	152	**60.8**
Dryandra nivea					14	**0.4**			43	**17.2**
Calothamnus sanguineus	801	**66.9**	1965	**89.8**	2955	**87.5**	84	**37.3**	43	**17.2**
Jacksonia floribunda	217	**18.1**	17	**0.8**	298	**8.8**				
Astoloma microdonta	11	**0.9**								
Total grains counted	1198		2188		3376		225		250	

Appendix 6. Grain counts and percentages (bold) of pollen types carried by *T. rostratus.*

Pollen of plant species carried each month.	Site 1 grains	Site 1 %	Site 2 grains	Site 2 %	Site 3 grains	Site 3 %	Site 4 grains	Site 4 %	Site 5 grains	Site 5 %
Jan-88										
Banksia attenuata							128	**17.7**		
Banksia grossa	27	**3.1**	33	**16.5**	11	**2.5**			11	**4.8**
Dryandra sp. unid.	432	**48.9**	78	**39.0**	55	**12.5**			14	**6.1**
Eucalyptus todtiana							568	**78.4**	197	**86.4**
Eucalyptus tetragona	341	**38.6**	55	**27.5**	290	**65.8**				
Verticordia densiflora	24	**2.7**	26	**13.0**	81	**18.4**				
Beaufortia elegans	49	**5.5**								
Total grains counted	883		200		441		724		228	
Mar-88										
Banksia leptophylla	67	**55.8**			76	**41.1**				
Dryandra sp. unid.			33	**62.3**	26	**14.0**				
Adenanthos cygnorum	16	**13.3**			14	**7.6**				
Eucalyptus tetragona					65	**35.1**				
Beaufortia bracteosa	28	**23.3**								
Total grains counted	120		53		185					
May-88										
Dryandra nivea	39	**40.6**					30	**42.2**		
Dryandra sp. unid.	13	**13.5**					12	**16.9**		
Banksia grossa	16	**16.7**					28	**39.4**		
Calothamnus sanguensis	28	**29.2**								
Total grains counted	96						71			
Jul-88										
Banksia candolleana							54	**45.8**	59	**64.1**
Banksia grossa							48	**40.7**	11	**12.0**
Dryandra nivea									13	**14.1**
Total grains counted							118		92	
Sep-88										
Dryandra falcata	2	**33.3**								
Dryandra carlinoides	2	**33.3**								
Dryandra nivea	2	**33.3**					21	**20.4**	63	**37.3**
Dryandra sp. unid.							15	**14.6**		
Verticordia grandis							53	**51.4**	26	**15.4**
Calothamnus sanguineus									52	**30.8**
Total grains counted	6						103		169	
Nov-88										
Banksia attenuata	13	**59.0**					728	**82.4**	370	**89.8**
Banksia grossa									19	**4.6**
Verticordia densiflora					30	**96.8**				
Beaufortia elegans							130	**14.7**	13	**3.2**
Total grains counted	22				31		884		412	
Jul-87										
Banksia candolleana							19	**18.8**	131	**59.8**
Banksia hookeriana							76	**75.2**		
Dryandra sp. unid.									14	**6.4**
Total grains counted							101		219	
Sep-87										
Adenanthos cygnorum							12	**6.0**		
Calothamnus sanguineus							161	**80.9**		
Total grains counted	6						199			

Appendix 7. Grain counts and percentages (bold) of pollen types carried by *M. musculus*.

Pollen of plant species carried each month.	Site 1		Site 2		Site 3		Site 4		Site 5	
	grains	%	grains	%	grains	%	grains	%	grains	%
Jan '88										
Banksia grossa			1	**50.0**	3	**75.0**			5	**62.5**
Dryandra sp. unid.									1	**12.5**
Calothamnus quadrifidus			1	**50.0**	1	**25.0**				
Calothamnus villosus									2	**25.0**
Total grains counted			2		4				8	
Mar '88										
Banksia grossa	1	**100.0**								
Total grains counted	1		0						0	
May '88										
Banksia candolleana							18	**90.0**		
Banksia grossa									10	**91.0**
Banksia hookeriana	4	**50.0**								
Dryandra nivea	1	**12.5**							1	**9.0**
Adenanthos cygnorum	1	**12.5**								
Calothamnus sanguineus	1	**12.5**					2	**10.0**		
Astroloma microdonta	1	**12.5**								
Total grains counted	8						20		11	
July '88										
Banksia candolleana	11	**52.4**					1	**14.3**	15	**71.4**
Banksia grossa	4	**19.0**					4	**57.1**	4	**19.0**
Dryandra nivea	2	**9.5**								
Dryandra sp. unid.	3	**14.3**					2	**28.6**	2	**9.5**
Calothamnus sanguineus	1	**4.8**								
Total grains counted	21						7		21	
Sept '88										
Banksia candolleana									14	**60.9**
Banksia grossa									7	**30.4**
Dryandra falcata					28	**96.6**			1	**4.3**
Dryandra sp. unid.					1	**3.4**			1	**4.3**
Total grains counted					29				23	
July '87										
Banksia candolleana	1	**14.3**					2	**66.7**	5	**100.0**
Banksia grossa							1	**33.3**		
Dryandra falcata	4	**57.1**								
Dryandra sp. unid.	2	**28.6**								
Total grains counted	7						3		5	
Sept '87										
Banksia grossa			5	**45.4**					2	**50.0**
Calothamnus sanguineus			6	**54.5**					2	**50.0**
Total grains counted			11				0		4	
Nov '87										
Banksia grossa	2	**8.7**	13	**65.0**					11	**78.6**
Dryandra sp. unid.	2	**8.7**	2	**10.0**					1	**7.1**
Adenanthos cygnorum									1	**7.1**
Calothamnus quadrifidus	18	**78.3**	2	**10.0**						
Calothamnus sanguineus			3	**15.0**						
Calothamnus villosus									1	**7.1**
Eucalyptus macrocarpa	1	**4.3**								
Total grains counted	23		20						14	

Appendix 8. Grain counts and percentages (bold) of pollen types carried by *P. albocinereus*.

Pollen of plant species carried each month.	Site 1 grains	%	Site 2 grains	%	Site 3 grains	%	Site 4 grains	%	Site 5 grains	%
Jan '88										
Banksia attenuata							7	**16.3**		
Bankisa grossa							2	**4.6**	7	**87.5**
Dryandra sp. inid							14	**32.6**		
Adenanthos cygnorum							2	**4.6**	1	**12.5**
Eucalyptus tetragona	23	**100.0**								
Eucalyptus todtiana							13	**30.2**		
Melaleuca tricho...							2	**4.6**		
Jacksonia floribunda							3	**7.0**		
Total grains counted	23						43		8	
Mar '88										
Banksia grossa	3	**11.1**								
Banksia leptophylla	18	**66.7**								
Adenanthos cygnorum	5	**18.5**								
Eucalyptus tetragona	1	**3.7**								
Total grains counted	27				0		0			
May '88										
Banksia grossa	2	**66.7**					49	**81.7**		
Banksia menzeisii							2	**3.3**		
Banksia hookeriana							1	**1.7**		
Dryandra sp. unid.							6	**10.0**		
Calothamnus sanguineus							2	**3.3**		
Eucalyptus macrocarpa	1	**33.3**								
Total grains counted	3						60			
July '87 & '88										
Banksia candolleana							8	**14.3**	21	**70.0**
Banksia grossa							6	**10.7**		
Banksia hookeriana							6	**10.7**		
Banksia leptophylla							8	**14.3**	7	**23.3**
Dryandra nivea							3	**5.4**		
Dryandra carlinoides							1	**1.8**		
Dryandra sp. unid.							19	**33.9**	2	**6.7**
Calothamnus sanguineus							5	**8.9**		
Total grains counted							56		30	
Sept '87 & '88										
Banksia grossa	3	**30.0**							1	**12.5**
Banksia leptophylla	5	**50.0**								
Dryandra sp. unid.	1	**10.0**								
Adenanthos cygnorum									3	**37.5**
Calothamnus sanguineus	1	**10.0**					1	**100.0**	4	**50.0**
Total grains counted	10						1		8	
Nov '87										
Banksia attenuata							14	**46.7**		
Banksia grossa	68	**84.0**	5	**62.5**	76	**96.2**	1	**3.3**		
Banksia hookeriana									1	**14.3**
Adenanthos cygnorum	1	**1.2**							5	**71.4**
Calothamnus sanguineus	10	**12.3**	1	**12.5**	3	**3.8**	11	**36.7**	1	**14.3**
Verticordia muelerina							1	**3.3**		
Beaufortia elegans	2	**2.5**	2	**10.0**			2	**6.7**		
Conostylis sp.							1	**3.3**		
Total grains counted	81		8		79		30		7	

Appendix 9. Grain counts and percentages (bold) of pollen types carried by *S. granulipes*.

Pollen of plant species carried each month.	Site 1 grains	Site 1 %	Site 2 grains	Site 2 %	Site 3 grains	Site 3 %	Site 4 grains	Site 4 %	Site 5 grains	Site 5 %
Jan '88										
Banksia attenuata	1	**0.9**								
Bankisa grossa	79	**72.5**								
Dryandra sp. inid	18	**16.5**								
Grevillea shuttleworthiana	4	**3.7**								
Eucalyptus tetragona	6	**5.5**								
Eucalyptus todtiana							5	**100.0**		
Beaufortia elegans	1	**0.9**								
Total grains counted	109						5			
Mar '88										
Banksia leptophylla	5	**100.0**								
Total grains counted	5						0			
May '88										
Banksia grossa							14	**45.2**	26	**70.2**
Banksia menzeisii									3	**8.1**
Banksia hookeriana									1	**2.7**
Dryandra nivea							5	**16.1**	1	**2.7**
Dryandra sp. unid.							11	**35.5**	6	**16.2**
Calothamnus sanguineus							1	**3.2**		
Total grains counted							31		37	
July '87 & '88										
Banksia candolleana	41	**41.8**					3	**75.0**		
Banksia grossa	7	**7.1**								
Banksia leptophylla	2	**2.0**								
Dryandra falcata	16	**16.3**								
Dryandra nivea	29	**29.6**								
Dryandra sp. unid.	2	**2.0**								
Lambertia multiflora	1	**1.0**								
Hibbertia sp.							1	**25.0**		
Total grains counted	98						4			
Sept '87 & '88										
Banksia grossa							1	**1.9**		
Calothamnus sanguineus							35	**66.0**		
E. acutiflora							1	**1.9**		
V. muel.							16	**30.2**		
Total grains counted							53			
Nov '87										
Banksia attenuata							28	**28.9**	5	**7.1**
Banksia grossa	102	**35.4**					1	**1.0**		
Dryandra sp. unid.	1	**0.4**					1	**1.0**	1	**1.4**
Adenanthos cygnorum	1	**0.4**					5	**5.1**	28	**40.0**
Calothamnus villosus									14	**20.0**
Beaufortia elegans	42	**14.6**					30	**30.9**		
Melaleuca trich	51	**17.7**					15	**15.5**		
Verticordia densiflora	40	**13.9**					15	**15.5**	18	**25.7**
Verticordia muel	41	**14.2**								
Verticordia grandis	10	**3.5**					2	**2.1**	4	**5.7**
Total grains counted	288						97		70	