MICROBATS

IN CHANGING COTTON PRODUCTION LANDSCAPES

A case study from the Namoi River

by

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Words and ultrasounds -

that we may listen and learn

Very early in the project Nicholas Birks' "*Nyctophilus geoffroyi* (lesser longeared) with moth" (Wildflight) image became the visual logo for the project within the cotton industry.

Acknowledgements

I dedicate this work to my maternal grandmother, my grandfathers, my parents and my wonderful daughters, who have all provided in various ways courage, strength, interest and extensive support.

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TABLE OF CONTENTS

Microbat Diversity and Community Structure

Microbats and vegetation across the landscape

Chapter 6.7.B. Species distribution

ADDENDA TO THESIS ON CD

Chapters 6.4. and 6.5. have been excluded from the body of the thesis due to their inconclusive and speculative results. However because of their significance for both microbat ecology and the cotton industry they have been included as Addendum A and B on the accompanying CD.

Addendum A Chapter 6.4 Insects and predator-prey relationships

Addendum B Chapter 6.5 The influence of climate and moon and other variables

LIST OF TABLES

Chapter 1 Introduction

Chapter 3 The study site

Chapter 4 Methodology - drawing patterns across the landscape

Chapter 5 Listening to changes along the Namoi - a reconstruction of a cotton landscape

Microbat Diversity and Community Structure

Chapter 6.1 Microbat Diversity

Chapter 6.2 Microbat patterns of activity

Chapter 6.3 Microbat patterns of feeding activity

Chapter 6.6 Structuring microbat communities

Microbats and vegetation across the landscape
Chapter 6.7.A Call abundance distribution

Chapter 6.7.B Species distribution

Chapter 8. Conclusion and Recommendation

ON ACCOMPANYING CD

Addendum A Chapter 6.4 Insects and predator-prey relationships

Addendum B Chapter 6.5 The influence of climate and moon and other variables

LIST OF FIGURES

Chapter 1 Introduction

Chapter 2 Project Aims

Chapter 3 The Study Site

Chapter 4 Methodology - drawing patterns across the landscape

Chapter 5 Listening to changes along the Namoi - a reconstruction of a cotton landscape

Attachment 5

Microbat diversity and community structure

Chapter 6.1 Microbat Diversity

Chapter 6.2 Microbat patterns of activity

Chapter 6.3 Microbat patterns of feeding activity

Attachment 6.3.

Chapter 6.6 Structuring microbat communities

Microbats and vegetation across the landscape

Chapter 6.7.A Call abundance distribution

Chapter 6.7.B Species distribution

Attachment 6.7.Bi

Attachment 6.7.Bii

ON ACCOMPANYING CD

Addendum A Chapter 6.4 Insects and predator-prey relationships

Attachment 6.4.

Addendum B Chapter 6.5 The influence of climate and moon and other

LIST OF PLATES

Frontice

Chapter 1 Introduction

Chapter 3 The study area

Chapter 4 Methodology - drawing patterns across the landscape

Chapter 5 Listening to changes along the Namoi– a reconstruction of a cotton landscape

Microbat diversity and community structure
Chapter 6.1 Microbat Diversity

Chapter 6.3. Microbat Patterns in Feeding Activity

ON ACCOMPANYING CD
Addendum A Chapter 6.4 Insects and predator-prey relationships

ABSTRACT

This study has investigated the links between microbats, cotton production and native vegetation across three cotton production properties (56 km ^{2}) adjacent to the Namoi River between Narrabri and Wee Waa on the north west plains of NSW.

Four landscape surveys were conducted, an autumn 2003 exploratory survey, and three seasonal surveys during the 2003/04 cotton-growing season. Microbat ultrasound echolocation was recorded with an Anabat recorder for 20 minutes at 102 exploratory sites, and 64 seasonal sites between either civil twilight or sunset and midnight. Climatic and moon cycle data was collected during each 20 minute sample. The sites were identified through a stepwise random sampling design, the number limited to a proportional representation of the seven native vegetation and three intensive management landscape elements within the study area. A capture survey was conducted in conjunction with the spring 2003 seasonal survey.

A microbat assemblage of between 14 and 17 species was identified in the study. These species were divided into guilds based upon the ultrasound frequency used, and the frequency relationship to insect hearing. The study suggested that species in the guild utilising the lower frequencies that are within insect hearing have adapted foraging patterns and used cotton fields significantly during crop production. The species in this guild recorded in total the highest call abundance and the most extensive spatial distribution across all landscape elements and all seasons, and movement from cotton fields to vegetation remnants in autumn after crop production. However a comparison between activity associated with (i) conventional and (ii) two gene Bollgard II™ cotton varieties suggested reductions in activity over cotton crops. Impacts upon the bat assemblage due to the use of GM cotton varieties are unknown. The guilds of species utilising higher ultrasound frequencies with foraging patterns below the canopy, or within vegetation and the understorey, recorded the lowest presence across the whole landscape, particularly in summer. Very few remnants within the study area contained a shrubby understorey.

Nocturnal patterns of activity varied between species and for individual species between seasons, with the season of highest call abundance varying between species. A species index showed the highest species richness occurred in spring as well as in autumn. A distribution index showed the landscape element recording the highest species richness was river gum open woodlands (14) in spring, but in autumn a species richness of 13 was recorded for the poplar box and mixed species categories. Five other landscape categories recorded 12 species, irrigated cotton and mixed species in spring, poplar box in summer, and river gum open woodland and dryland cropping in autumn. The summer absence of one species, *Tadarida australis* was most likely due to a combination of rainfall, temperature and humidity parameters. Other seasonal variations in presence could be associated with cotton insect population movement but could not be ascertained. Activity patterns for the assemblage, for individual microbat species, and for insects were examined nocturnally, seasonally and spatially, and in relation to climatic conditions.

Captured bats included a black morph *Chalinolobus gouldi*, three lactating *Chalinolobus morio*, and three *Nyctophilus* spp. *N. geoffroyi*, *N. gouldii* and *N. timoriensis.* For many areas the status of four species identified in the study (*N. timoriensis*, *Saccolaimus flaviventris*, *Chalinolobus picatus*, *Vespadelus troughtoni*) is listed as vulnerable.

Microbat contribution to reductions in the cotton pest moths *Helicoverpa* spp. may be twofold, by (i) direct predation, and (ii) interruptions to nocturnal reproductive activities resulting from avoidance behaviour at the detection of microbat ultrasound echolocation. On the other hand microbat roosting site requirements, limited to tree hollows, bark and human structures in the study area, suggests that an ecosystem service is being provided to cotton production by vegetation remnants containing old trees. Although cotton landscapes still contain indigenous vegetation remnants, strong incentives are required for their maintenance. The identified microbat presence and activities could provide not only a link between production and conservation, but also economic and environmental incentives for improved management practices of remnant vegetation.

The results of this study begin to provide an understanding of the complex relationships between individual species and an assemblage of microbats in an intensive agricultural landscape matrix. Many results have important implications in the management of both remnant vegetation and GM cotton varieties.

CHAPTER 1 INTRODUCTION

Contents

1.1 A COMPLEX SETTING

Benchmark in time

This study has investigated the microbat (microchiropteran) community of a cotton growing region adjacent to the Namoi River on the north-western plains of NSW. It has attempted to examine some of the relationships between microbats, cotton production and vegetation remnants, at point of change in a constantly changing Australian intensive agricultural landscape. This change has been instigated by two major management challenges, (i) insect pests of cotton production, and (ii) a plant pest of riparian zones.

The first challenge was the management of two *Helicoverpa* moth species (one indigenous the other introduced), the major pests of cotton production. As an outcome of research instigated by economic and environmental pressure, the cotton industry has adopted the transgenic Bt cotton varieties - initially Ingard™ (from the late 1990s) but more recently the two-gene Bollgard II™ (in the 2003/04 and 2004/05 cotton seasons). The broad-scale adoption of these technologies, together with a system of integrated pest management, has resulted in reduced landscape scale chemical usage (Ref). Although conventional cotton varieties still attract large pest moth populations, the immediate consequence will be changes in insect populations and communities, in and around cotton fields.

The second challenge, a corollary of flooding rivers, is the predominantly unchecked and recently aggressive spread across flood plains of the exotic ground cover plant lippia (*Phyla canenscens*). This invasion has resulted in an apparent rapid diminution in riparian tree health, a presumed reduction in biodiversity, and a drastic reduction in production viability of grazing lands across flood plains. The only management tool currently available for land not at high risk from flooding, is a disruptive regime that includes plowing and cropping and its associated preparation and dead timber clearance (Ref).

The outcomes of these two management challenges have consequences for any resident biodiversity. An unknown component of that biodiversity, a microbat community in a cotton production landscape, is the subject of this research project. The community is documented immediately prior to the landscape scale adoption of two-gene Bt cotton varieties when insect populations included very high populations of moths; also at the commencement of lippia management when riparian landscapes included high numbers and diversity of hollows in old senescing and dead standing and fallen trees, but a greatly reduced diversity of vegetative understorey.

In Australia very little research has previously been undertaken into communities of microbats and, with the exceptions of a study in mixed agricultural grazing and cropping landscape of Victoria's northern plains (Lumsden *et al.* 1995) and a biodiversity study of eucalypt plantings to reduce salinity in agricultural grazing land around Albury Wodonga (Cavanagh *et al.* 2005), almost none has been conducted in continually changing agricultural landscapes. The results of this project will therefore provide a very important benchmark for a microbat community within an intensively managed and changing agricultural landscape.

Challenges for change

The integration of conservation with development, and of intensive agricultural practices with the functioning of natural ecosystems and the diversity of species, are portended to be emerging as the greatest conservation challenges in human dominated landscapes. It has been declared that unless agricultural practices develop more benign interactions with the natural environment, even the substantial development of protected area systems will be unable to halt environmental decline and the loss of species (e.g. Bauer and Goldney 2000). This process has been particularly pronounced in the semi-arid woodlands of eastern Australia (of which the study region is part) where excessive clearing for sheep and wheat farming has resulted in massive loss of species, particularly mammals (Dickman 1994, Flannery 1994**,** Bergman and Lindenmayer 1998, Bauer and Goldney 2000, Date *et al.* 2000). It is therefore imperative to develop conservation strategies for intensively managed production landscapes which are able to maintain at least substantial subsets of the entire diversity.

During the past ten years considerable progress has been made in the understanding of the interface and interaction between farming and biodiversity. The inclusion of landscapes as the most suitable ecological context has provided a more suitable ecological and policy framework. Applications of economic models and methods of thinking considered to enhance environmental benefits (Barbier 1989) are increasing. There is however still a paucity of examples where changes have been made, not just for farms, but for entire farming regions and agricultural industries. Whilst there are many reasons for such lack of implementation, the slow rate of demonstrable benefits to farmers from conservation practices remains one of the most powerful inhibitors. This missing link has been identified in many developing countries (Sakulas *et al.* 2000). It is less recognised, although equally powerful, in western-type industrialised nations.

The following study will provide results of action research that set out to demonstrate such a missing link for one of the most controversial and generally condemned industries – cotton production. It has identified microbats as a missing link “par excellence” as microbats have demonstrable benefits to farmers (depression of cotton insect pests), and are linked via a requirement for roosting habitat, to the retention of woodlands impacted upon by intensive agricultural production including cotton production. It rests on the premise that a better understanding by growers of the benefits of this group of species will increase grower “willingness” to invest in better conservation practices. It rests also on the assumption that bat research, through its use of modern visual and auditory computerised technology can be a powerful means of communicating this message.

In order to do so however, extensive surveys of microbats are required and a better knowledge of microbats, their distribution, diversity and function across cotton landscapes is fundamental. The results of this study are set in the context of the regional cotton industry and the current state of our understanding of microbat diversity and distribution in the semi-arid parts of eastern Australia.

The human stakeholders

Many stakeholders in agricultural industries are actively seeking to better integrate nature conservation and production outcomes, and to address the interrelated problems of land degradation and biodiversity loss (DE&H 2003, AFFA 2003). This is supported by a range of policy and legislative initiatives and a sea-change in land-holder and agricultural industry attitudes (Reid *et al.* 2003, AFFA 20003).

The cotton industry is seeking to address a range of environmental problems and is arguably at the forefront of this change. Of particular importance for the management of pest insects in cotton field environments, is the change from a reliance upon chemicals, to a more extensive and integrated approach that includes the maintenance of beneficial organisms (Mensah and Wilson 1999, Johnson *et al.* 2000, Farrell & Johnson 2005). Current research is quantifying the benefits of native vegetation surrounding cotton fields as habitat for beneficial insects thus giving native vegetation a production as well as a conservation value (Rencken 2003).

Ecologists too are seeking to better understand and facilitate the integration of production practices and processes and conservation objectives, so that critical ecosystem system cycles function appropriately, and production is sustainable (Main 1993, Hobbs and Saunders 1993, Bennett 1999, Dale *et al.* 2001, Bissonette and Storch 2003, and Farina 2003, Hobbs *et al.* 2003)

1.2 THE PROTAGONISTS

The interrelationships between the protagonists and the arenas of interest involved in this research study are set out in Fig. 1.2. A brief overview below introduces the major protagonists.

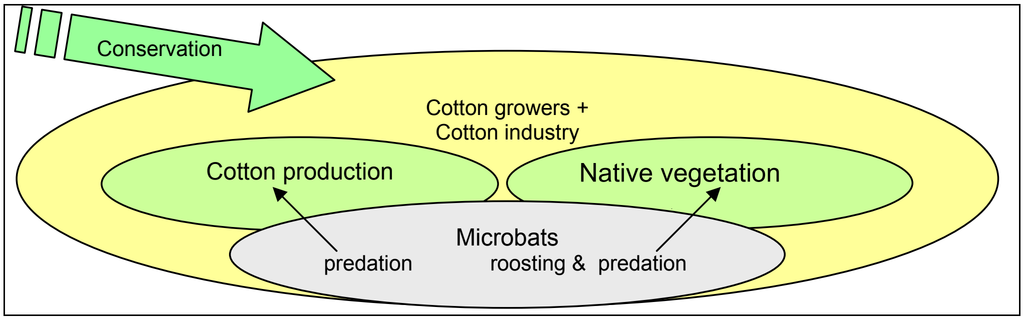

Fig. 1. 2. Interrelationships between the protagonists and arenas of interest – microbats, cotton production, native vegetation remnants, cotton growers and the cotton industry, and conservation pressures.

Microbats

Bats (Chiroptera) make up the world's second largest group of mammals comprising 950 species in 18 Families recorded worldwide. Australia has a rich microbat fauna with a high species diversity accounting for 90 taxa and 7 Families (Duncan *et al.* 1999). Although the 65 Australian microbat species described in Churchill (1998) are distributed across six families, 35 species belong to the Family Vespertilionidae (evening bats). The others species - eleven Molossidae (freetail), eight Emballonuridae (sheathtail), seven Hipposideridae (leafnosed), three Rhinolophidae (horseshoe), and one Megadermatidae (large winged) species – are distributed across the remaining Families. With a few exceptions Emballonuridae, Megadermatidae, Rhinolophidae and Hipposideridae species inhabit northern Australia whereas the known ranges for Vespertilionidae and Molossidae species are much more varied. In NSW 29 species have been recorded (Ref Herr).

Microchiroptera or microbats, the focus for this study, are small predominantly insectivorous nocturnal airborne mammals, that use ultrasound echolocation for navigation and prey location. Reproduction is slow, most species giving birth to a single young annually with infrequent twin occurrence . Microbats typically live from 5 to 10 years, however many live longer. To offset the high energy cost of flight , individuals of some species eat between 50% to 70% of their body weight, sometimes more, in insects each night (Churchill 1998, Kunz *et al.* 1995b, Lee and McCracken 2005). Although most microbats are opportunists and often dependant upon insect species abundance, moths and beetles feature prominently as dietary components. Daily torpor and winter hibernation, as well as careful roost selection, are used to minimise metabolic rate (Willis, *et al.* 2005, Turbill *et al.* 2003a & b). Roost selection varies, seasonally, as well as inter and intraspecifically, according to biological and climatic variability (Kortner and Geiser 2000, Turbill and Geiser 2005).

Cotton

Cotton Production

After China and the U.S.A., Australia is the third largest exporter in the world cotton marketplace with a current production of approximately 3 million bales p.a. (70% from N.S.W and the remainder from Queensland). The Australian Cotton Research & Development Corporation (CRDC) estimated a five-year production average for 1998 to 2002 (including some drought years) of 3.2 million bales from 470,000 hectares of cotton. The Australian Bureau of Agriculture and Resource Economics estimated the average Gross Value of Production for that period as $1.57 billion p.a. (CRDC 2003). CRDC estimated that since 1980 the value of Australian cotton produced annually has increased dramatically to about $1.4-$1.6 billion per annum.

Although small areas of cotton had been grown earlier, today's Australian cotton industry developed opportunistically in direct response to the construction of large water storages between 1961 and 1977 along eastern Australian inland rivers. Although cotton production typically occupies 5% or less of catchments where it is grown, with its dependence upon water that 5% of land is located primarily along rivers.

Cotton growth cycles

Cotton plants require 175 frost free days per year, hot summers, low humidity and long hours of sunshine. Irrigated and dryland cotton production in Australia therefore occurs between the latitudes of 45° north and 30° south. Planting is carried out in spring when soil temperatures required for germination reach 14C° at 10cm depth. Crops take 180 days from emergence to maturity. Between December and February/March irrigated cotton crops are watered every two to three weeks, resulting in five or six irrigations per season. On reaching maturity crops are defoliated and picked between March and May, depending on seasonal conditions. Cotton is predominantly grown in rotation with wheat, a winter crop, followed by a fallow (Table 1.2a).

Table 1 2.a. Seasonal patterns - cropping system and microbats

Season	Summer		Autumn			Winter			Spring			Summ
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cotton	🟩	🟩	🟩	🟩						🟩	🟩	🟩
Wheat					🟨	🟨	🟨	🟨	🟨	🟨		
Sorghum	🟧	🟧	🟧	🟧						🟧	🟧	🟧
Microbat activity	▨	▨	▨	▨	?	Hibernation?			?	▨	▨	▨

Other crops used in irrigation and dryland cropping systems are barley, chick peas and soya beans in winter, and sorghum, sunflowers, and pidgeon peas in summer. It is presumed that winter crop production is of little use to hibernating insectivorous microbats.

Cotton production and native vegetation

Farms on which cotton is grown are between 500 to 2000 hectares in size, highly mechanised, capital intensive, technologically sophisticated and require high levels of management expertise. About 80% of these farms are irrigated (CRDC 2003). Most are owned and independently operated as family businesses with around 1,200 distributed across NSW and Queensland. These enterprises combine dryland and irrigated rotational crop production, and many include cattle grazing.

Thus cotton production landscapes have developed incorporating large off-river water storages and/or bores linked to water supply systems and areas of irrigated and dryland winter and summer cropping. These cropping areas are interspersed with indigenous vegetation remnants on soils not utilised for crop production i.e. prone to flooding or sandy ridges. Vegetation remnants are often utilised for cattle grazing (Plate 1a).

Plate 1.a. Cotton production landscape - “Mollee” and “Cardale” autumn 2004 LtoR Fallow field, picked cotton and modules, river red gum forest in background, water suppy channel, poplar box remnant. (Site Hg)

Cotton growers and industry stakeholders

Cotton growers fall into two categories.

- *Small cotton farms* are usually family mixed enterprise businesses, often run by two generations, sometimes with extended family members and often employ several staff. These farms regularly have areas of remnant vegetation, particularly adjacent to a river.
- *Large cotton farms* are mostly corporate companies, often more than one large farm, usually restricted to rotational irrigated cropping with varying percentages of remnant vegetation e.g. Auscott has large farms at Narrabri (adjacent farm just purchased for vegetation) and Moree (includes quite large areas of remnant vegetation). Organisation includes board of directors, a CEO, often a manager, environmental officer and sometimes several agronomists per farm, along with teams of workers or contractors employed for differing aspects of the farm. Research on these farms is often actively encouraged.

Cotton growers are supported by an industry comprised of the following stakeholders:

- *Australian Cotton Cooperative Research Centre* - a multi organisational research centre coordinating scientific research by CSIRO, NSW Department of Agriculture, Queensland Department of Primary Industries, NT Department of D.P.I.S., CRDC, Universities of Sydney, New England and Charles Sturt, and in conjunction with many Government and non-Government organisations. Funding is jointly provided by the Australian Government, core partners, and other partnership agreements.

- *Cotton Research and Development Corporation* (CRDC) - the cotton industry research and development organisation financed by levies paid by cotton growers and matched proportionally by Commonwealth Government funding. The research direction is determined by the Australian Cotton Grower Research Association (ACGRA), a body of grower representatives.

- *Cotton Australia* - a cotton industry promotional organisation funded by an industry voluntary levy.

- *Consultants* - individuals or companies contracted by individual growers to provide agronomic and pest management reporting and advice for crop production.

- *Industry service personnel* - include representatives of seed, chemical and machinery companies as well as spray contractors, etc.

- *Irrigator groups* - voluntary self-funded industry groups focused upon water management issues.

- *Catchment Management Authorities*.

- *Government agencies* - including State and National agencies funded by the Government associated with production or environmental issues; Commonwealth Department of Agriculture, Forestry and Fisheries; Queensland State Government, and the National Action Plan for Salinity.

- *Funding bodies* - other CRC's: Freshwater Ecology, Irrigation Futures, Grain R&D Corp, as well as Land & Water Australia, National Programme for Sustainable Irrigation; Murray Darling Basin Northern Laboratory; and the National Heritage Trust.

Conservation

Conservation in New South Wales is managed through the Catchment Management Authority (CMA) structure whereby progress is assessed and measured against natural resource management targets and objectives identified in the adopted Catchment Management Blue Prints and Catchment Management Plans (many of which are still to be passed in Parliament). Catchment targets for biodiversity and riverine ecosystems are set out in the Namoi CMA Annual Report 2004-05 below.

Biodiversity catchment target: " …by 2010 secure biodiversity by ensuring that the level of native vegetation cover as at March 2001 (currently estimated at 62%) is maintained across the Namoi Catchment with at least 15% of the catchment managed for conservation. The area of native vegetation is to be reasonably distributed across the whole of the catchment. This includes programs for managing existing native vegetation . . . and strategic additional native vegetation to secure distribution and quality of biodiversity."

Riverine ecosystems catchment target: "…by 2010 have a five per cent improvement in the Average Riverine Assessment Index for riverine condition with no deterioration in the current status of any sub-catchment. This includes programs to address structural stability, additional riparian vegetation, conservation of riparian vegetation and aquatic biodiversity."

1.3 STATUS OF PROTAGONISTS

Micobats

The status of microbats in Australia

Not only is public and scientific knowledge of this Australian mammal group limited, but available research indicates that many species are threatened (Duncan *et al.* 1999).

In 1991 Parnaby stated that at least two thirds of the then recognised Australian bat species were in need of taxonomy clarification. Even though several taxonomic studies had been undertaken, the Action Plan for Australian Bats (Duncan *et al.* 1999) declared that most studies had not only not added greatly to clarification but had instead elucidated further problems.

The conservation status in 1999 of the 90 Australian bat taxa listed in Action Plan for Australian Bats are shown in Fig. 1.3a (Duncan *et al*. 1999).

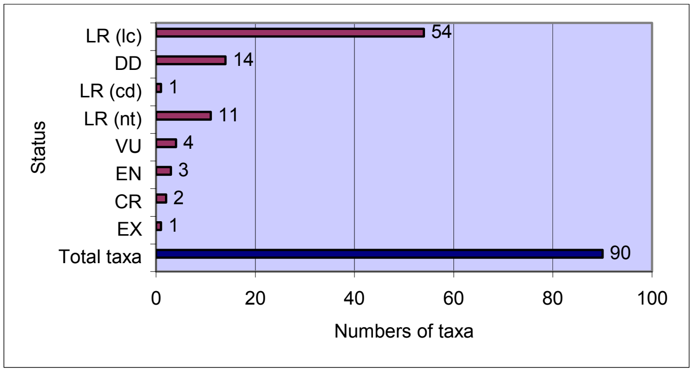

Fig. 1.3.a. Conservation status of Australia's 90 bat taxa (Duncan *et al.* 1999)
KEY: EX extinct; **CR** critically endangered; **EN** endangered; **VU** vulnerable; **LR** (nt) lower risk near threatened; **LR** (cd) lower risk conservation dependent; **DD** data deficient; **LR** (lc) lower risk least concern

Of the 90 bat taxa recognised by the Action Plan one taxa is listed as extinct, nine are either, critically endangered (2), endangered (3), or vulnerable (4), one is conservation dependent, eleven are considered to be 'near threatened' and fourteen taxa are listed as 'data deficient'. Thus 40% of Australian bat taxa are either of some conservation concern, or the knowledge to determine their conservation status is lacking.

The status of microbat research

Although microbat research has been greatly enhanced by the emergence of new technologies significantly increasing knowledge of microbats, there is much yet to be done. A meta-analysis of world-wide scientific journal articles listed in Recent Literature sections of the Australasian Bat Society Newsletters between 2001 and 2005 (Figs. 1.3b, c and d) indicates much of the research was concentrated on the biology of single species of comparisons betweentwo species , with very little directed towards conservation biology. Journal articles listed in the three most recent Australasian Bat Society Newsletters (July, November 2004 and April 2005) displayed separately, show other noticeable trends (Fig. 1.3b).

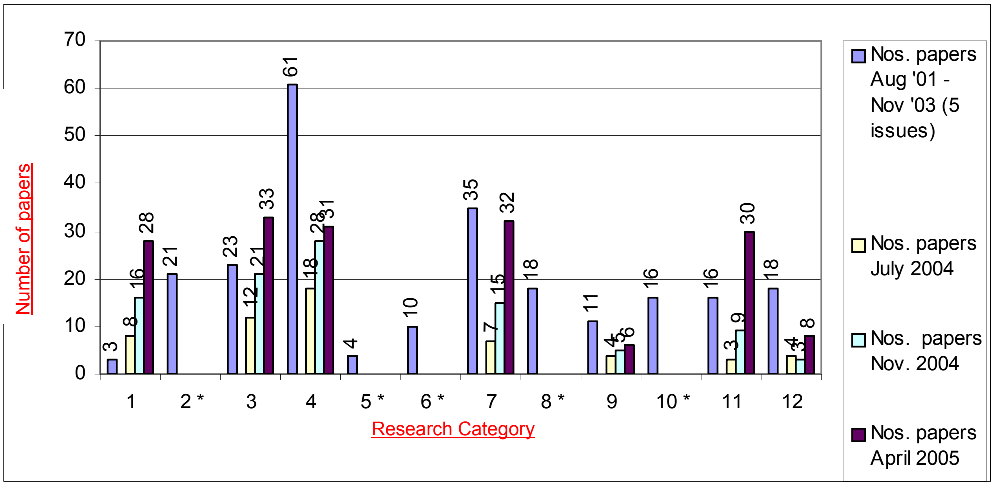

Fig. 1.3.b. Numbers of papers by research category for the three issues July and November 2004, and April 2005

KEY
Research category
1. acoustics & neurology
2. ecology, biogeography & conservation*
3. biogeography, conservation & management
4. ecology, reproduction & behaviour
5. fossil
6. genetics & evolution*
7. morphology, genetics & evolution
8. habitat ecology*
9. miscellaneous
10. morphology, foraging behaviour & diet*
11. parasites & viruses
12. physiology

* 2001/03 category

From July 2004 to April 2005 the ABS neswsletter listings showed a rapid increase in bat research generally and a 1.5 to 9-fold multiplication in research papers for particular categories, e.g. *acoustics & neurology* (2.5); *biogeography, conservation & management*

(1.5); *ecology, reproduction & behaviour* (0.92); *morphology, genetics & evolution* (3.6); and particularly *parasites & viruses* (9). The increase in research into parasites and viruses is most likely linked to recent concerns of virus transference from animals to humans – ie. concern for human preservation, not preservation of bats.

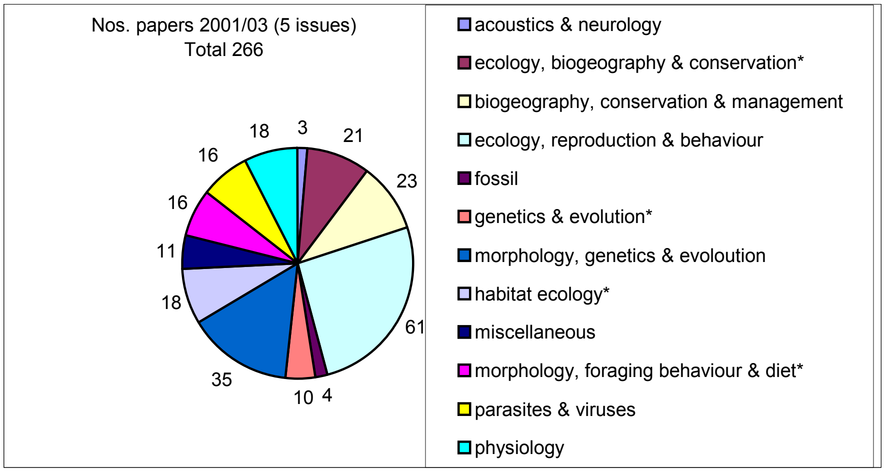

Fig. 1.3.c. Numbers of bat research articles listed in The Australasian Bat Society Newsletters Aug. 2001-Nov. 2003 (5 issues) divided by subject category * category used up to Dec. 2002

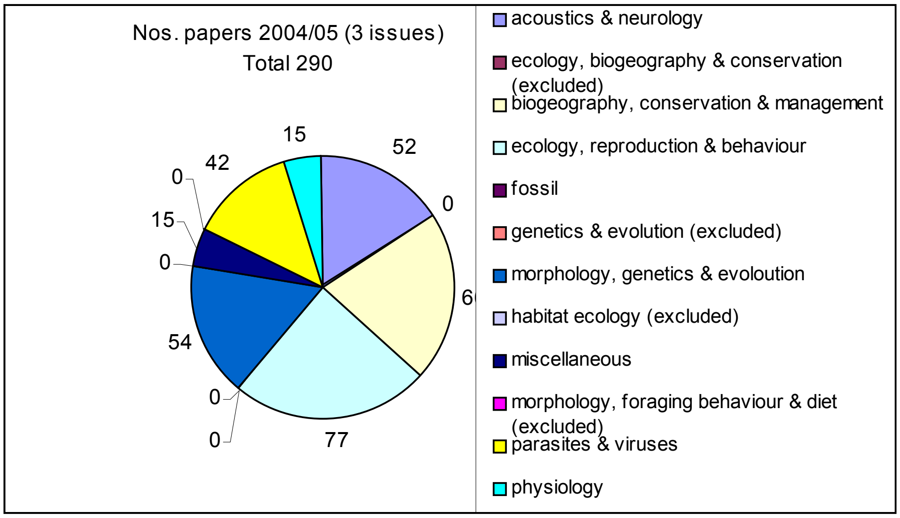

Fig. 1.3.d. Numbers of bat research articles listed in The Australasian Bat Society Newsletters July 2004-April 2005 (3 issues) divided by subject category

Not necessarily reflecting a world-wide perspective the ABS listings showed that although research on the role of bat interactions with moths has progressed researchwork on bat interactions with other insects remains in its infancy. Non-Australian bat species accounted for 32% (2001/03) and 46% (2004/05), and Megabat research (Megachiroptera) accounted for 9% and 14% of listed research respectively.

Overall, little research has been linked to conservation outcomes at a landscape level, with the greatest emphasis on spatial analysis and less on either short or long term temporal analysis. Only thirteen of 266 August 2001-November 2003 articles, and eighteen of 290 papers July 2004-April 2005, reported on research at the landscape scale. Of the thirteen 2001/03 landscape scale papers, four reported on research in forests and three reported on research in Australian grazing systems.

The 2004/05 landscape scale papers however cover a greater diversity of landscapes, with only four concentrating on forest type elements, one each in Canada, Paraguay, Europe and USA. During that timespan there was a continued absence of research on bats in Australian agricultural cropping systems, including cotton production systems. This would suggest an absence of knowledge of microbat communities in highly disturbed Australian agricultural landscapes. Woodland systems are essential for microbat diversity in Australia, and riparian landscapes are key elements of the landscape particularly cotton production landscapes. To maintain diversity it will be essential to reconcile landscape systems with the requirements of bat populations. To preserve microbat diversity it will therefore be essential to gain an understanding of cotton production impacts on bat habitats.

Cotton

The status of the cotton industry

Public concern has been focused upon the cotton industry's extensive use of chemicals and the subsequent impacts upon humans, terrestrial aquatic and soil organisms, waterways, vegetation and environmental systems generally. Table 1.3a sets out the cotton industry responses to improve its performance.

Table 1.3.a. The cotton industry's proactive responses to environmental issues

	1991	**1st Environmental Audit**
		(CRDC - 50% grower levy/50% Commonwealth Government)
		(1st Environmental Audit conducted in Australian agriculture)
	1993	}
1st Cotton CRC	1994/5	} **$6m. "Pesticides in the Riverine Environment" programme**
		} (Joint CRDC, L&W R&D Corp. Murray Darling Basin Commission)
	1996/7	}
		First **Guidelines for Best Management Practice** (BMP)
	1997	First **Manual for BMP**
		(Farm planning & layout, maintenance of water on farms, chemical use and storage)
2nd Cotton CRC	1998/9	
	1999	**Audit programme for BMP** including external audit
		Integrated Pest Management (IPM) Guidelines
	2002	**Cotton CRC failed supplementary bid "Enhancing Agricultural Landscapes"**
		However launched Cotton CRC Programme 6 (without funding) &
		with collaboration $5.8m. was committed to projects
	2003	**2nd Environmental Audit and Evaluation of BMP**
		(30% of growers fully audited - 50% of cotton area;
		90% of growers actively involved in some way)
	2003 Dec	**A Literature Review of Biodiversity Research in the Australian Cotton Industry**
		(Cotton CRC, CRDC & University of New England)
		launched at ESA Conference
		Managing riparian lands in the cotton industry
		(Cotton CRC, CRDC & Land & Water Australia)
	2004	**Cotton CRC new bid "Cotton Catchments & Communities**"
		"Land & Water" module of BMP (CRDC & Cotton Australia)
3rd Cotton CRC	2005	**Australian Cotton Catchments & Communities Cooperative Research Centre**
		successful – 2005-2010.
	2006	Establishment of new structure for **Cotton Catchments & Communities Cooperative Research Centre**

Note: 2003 project "**Bats, cotton production and vegetation remnants**"
acted as a pilot for many other possible NRM issue projects
CRC - Cooperative Research Centre
CRDC - Cotton Research & Development Corporation

The Australian cotton industry's voluntary grower-driven environmental program combining science with practical management, is aimed at delivering benefits for both the community and the natural environment. BMP includes modules on safe chemical storage and handling, recycling water, reducing chemical usage, minimising erosion, managing weeds and diseases, Integrated Pest Management (IPM), and in 2005, a new 'land and water' module.

The introduction of the genetically modified one-gene Ingard™ cotton varieties followed by the 2004/05 industry-wide adoption of two-gene Bollgard II™, all varieties breed to resist damage from the major cotton pest moth (*Helicoverpa* species), initially reduced chemical use by approximately 50%. More recently reductions have been from 10 to 20 applications per field per season, to two applications per field per season. However at the beginning of the 2004/05 season growers expended "a lot of money" on still expensive environmentally 'soft' species-targeted chemistry to manage heavy insect pressure on the required fields of conventional cotton varieties (a strategy to avoid chemical resistant insect populations). Such grower willingness to expend on expensive 'soft' targeted chemistry demonstrated commitment to and recognition of the late-season benefits provided by unhindered predator population expansions (Mensah & Wilson 1999, Johnson *et al*. 2000). However t yields from the new Bolgard II™ varieties in the 2005/06 cotton season were less than anticipated, suggesting difficult choices ahead for cotton growers.

In this environmental context, cotton industry operational practices and their interactions with the environment are crucial factors for the future. A better understanding of these interrelationships is essential and a particularly important factor is the vulnerability of cotton production to insect pests. Although direct links between insects and native vegetation are not yet well understood, it is apparent that any potential for beneficial organisms from native habitats is of great conservation relevance.

Conservation

The status of native vegetation remnants and biodiversity

This research study is located within the Darling Riverine Plains subregion of NSW.
The average condition of biodiversity within the riparian zones of that subregion was assessed in the National Land & Water Resources Audit Atlas (2000) as being "degraded" and requiring significant management intervention to achieve recovery. The average trend in the condition was assessed as "declining". Grazing pressure, exotic weeds, changed hydrology (other than salinity), and increasing fragmentation, were listed as threatening processes. The extent of native vegetation in 2000 was assessed as 30% - 70%, with vegetation having some connectivity associated only with landscape features. The intervening six years could only have witnessed a stationary state or a continuing decline in this situation.

Both the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999, and the NSW Threatened Species Conservation Act (1995), list key threatening processes (KTPs) and include the following impacts on biodiversity of the KTP 'native vegetation clearance': the destruction of habitat resulting in loss of local populations of species, fragmentation, riparian zone degradation, loss of leaf litter layer, loss or disruption of ecological function, and changes to soil biota.

Studies focusing on scattered trees, rather than remnant patches of trees, have indicated that the persistence of native trees in agricultural landscapes is threatened not only by vegetation clearing, but also by lack of tree recruitment and tree dieback (Reid and Landsberg 2000). Many of the remnants in the study area could be categorised as scattered trees (refer Plate 4Avii page 65). It seems surprising that in the above mentioned Atlas, the role of the cotton industry and its impacts on the riparian zones is not mentioned as a threatening process.

The general observations by Reid and Landsberg (2000) of processes resulting in the loss of scattered trees are born out in the study area where grazing of indigenous remnants has contributed to limited tree recruitment and many trees appear to display symptoms of dieback (refer Plates 4.Aii & iii). The retention of native tree cover – principally *Eucalyptus camaldulensis* and *Eucalyptus populnea*- in the area generally and in the riparian zone particularly, is the dominant conservation concern in the region.

In 2003 within the 56km^2 research area, remediation of lands infested with lippia (*Phyla canescens*), has resulted in the clearance of fallen and standing dead trees and very old and damaged living trees in 41% of the *E. camaldulensis* open woodland to enable introduction of a plowing and cropping regime directed at eventual pasture restoration. The manifestation of this strategy is a landscape of scattered or isolated trees in ploughed fields. During 2004 15% of the native grasslands within the study area were also cropped to manage lippia, and many growers are watching lippia management results, contemplating adoption of this environmentally and economically expensive procedure.

There is therefore an urgent requirement for research that will assist in the provision of a value for remnants of old indigenous vegetation as well as incentives for their sustainable management. The results of this project could fulfill these provisions. Options to assist the management of cotton insect pests are eagerly sought and therefore depending on landholder focus aquire a value. Lippia invasion of riparian zones is now problematic throughout the whole of the Murrray Darling Basin lower catchment (McCosker 1994).

1.4 POSSIBILITIES FOR LINKAGES AND INTERACTIONS BETWEEN PROTAGONISTS

Cotton and its associated insect populations

Cotton insect pests

Although more than 1,000 different species of insects and spiders can be found in Australian cotton fields only approximately 50 of these ever become abundant, and as few as 30 species of insects and mites have been recorded causing damage to cotton plants (Pyke and Brown 1996). Many spiders and insects are regarded as beneficial to cotton production and predate upon pest species. The majority, however, are benign, passing through cotton fields on the way to other habitats. Of the thirty species regarded as pests, three have been regarded of major importance and have required control measures in most regions in most seasons (Pyke and Brown 1996). These are the two noctuid moth species, the native budworm, *Helicoverpa punctigera* (Wallengren) and the cotton bollworm, *Helicoverpa armigera* (Hubner), and the two-spotted spider mite (*Tetranychus urticae*). Of secondary importance are the cotton aphid (*Aphis gossypii*), the green mirid (*Creontides dilutus*), spider mites (*Tetranychus* spp.), the silverleaf whitefly (*Bemisia tabaci b-biotype*), three thrip species which are also key predators of spider-mite eggs, and the green vegetable bug (*Nezara viridula*) (Pyke and Brown 1996 and Farrell and Johnson 2005). Since the widespread adoption of the *Helicoverpa* resistant Bollgard II™ cotton varieties in the 2004/05 cotton season, some of these secondary pests have required closer scrutiny and management, their occurrence and abundance however being highly variable.

Cotton insect management

The intensive seasonal management required for cotton production includes management of often large insect pest populations that cause extensive plant damage. In the past when insect pest thresholds were reached, extensive use of broad spectrum chemical sprays resulted, applied to individual fields from aircraft in the latter stages of crop production. Over the last ten years the focus of insect management has shifted from a dependence upon chemical control, to an integrated management approach using many strategies. These strategies include the use of: cotton varieties genetically modified to resist pests, target-specific chemicals, programmes and strategies to safeguard against chemical resistance in insects including trap crops and pupae busting, attractants, and the encouragement of beneficial predatory insect populations and other predatory organisms.

Cotton pest and beneficial organisms (IPM)

Along with the introduction of integrated pest management (IPM) strategies (Mensah and Wilson 1999) came the impetus for research into methods for retaining within cotton fields insect predators of *Helicoverpa* spp., such as ladybeetles, damsel, big-eyed, assassin and predatory shield bugs, green and brown lacewings, ants, lynx spiders and parasitoid wasps (Johnson *et al*. 2000). These methods included planting refuge crops as habitat for beneficial insects and the use of selective biological insecticides to minimise disruption of beneficial populations. A review of research into beneficial insects in cotton farming systems (Johnson *et al.* 2000) concluded that beneficials could have a major positive impact on IPM strategies saving farmers almost $A1 billion in the ten year period 2000/10. The review recommended biological and ecological research of common predators and parasites, and their distribution and movement in and between, cotton and other crops and natural vegetation, in order to increase understanding of the impact of beneficials on pest numbers and improve understanding of the effects of different pesticides on beneficials.

A Beneficial Disruption Index (BDI) providing a measure at the end of a season of the ‘softness’ and ‘hardness’ of an individual field’s insecticide spray regime, was introduced in 2003 (Dillon *et al.* 2004). A table outlining impacts of insecticides and miticides on predators in cotton (Wilson *et al*. 2005) was included in the 2005/06 Cotton Pest Management Guide (Farrell and Johnson, 2005). As yet the impacts on microbats have not been considered.

Several studies, including two in Australia (Dunsmore *et al.* 1974, Mispagel *et al*. 2004) have investigated the long-term impacts of chemicals on microbats and the relationship to declining microbat populations. The Australian studies have been limited to DDT and DDE, the most persistent residule of the DDT family. The results of research into impacts of 1960’s and 1970’s DDT useage on two southern bent wing (*Miniopterus schreibersii bassanii*) populations located in southern SA and Victorian caves concluded that, although DDE was detected in guano piles as well as body tissue, it seemed unlikely in 2004 that DDE was present at toxic concentrations.

Although chemical spray impact upon microbats is likely to have been greatly reduced with the adoption of IPM practices, the recently released pheromone attractants and their associated chemicals for *Helicoverpa* spp. management have introduced another danger for microbats. Due to the delay between chemical contact and death, microbat predation upon chemically affected moths could be fatal.

Investigation of native vegetation conducted between 1997 and 2001 found that predator and parasitoid native insects beneficial to cotton, utilised native vegetation near cotton fields (Stanley 1997, Yee 1998, Walker *et al.* 1998b and Silberbauer 2001). A current PhD research project is investigating the role of native vegetation in harbouring beneficial insects and reducing pest damage in cotton (Rencken 2003). This microbat project extends the recent focus on native vegetation as habitat for beneficial organisms.

Microbats and cotton insect populations

Microbats and food sources

Methods to determine food sources utilised by microbats are arduous and require, the identification of prey in either stomach contents, faecal samples or non-digested parts under roosts (Bayefsky-Anand 2005). Stomach content analysis has been conducted on specimens held in museum collections (Pavey *et al.* 2004) or specimens captured in field surveys (Vestjens and Hall 1977, Pavey *et al.* 2004). Faecal samples are collected under diurnal roosts, (Freeman Long *et al.* 1998) or from bats held in cloth bags between capture and release (Lumsden 1993, Pavey, *et al.* 2004, Lee and McCracken 2005). Prey components within faecal samples can be assessed by the identification of remaining parts (Whitaker 1988, Freeman Long *et al.* 1998, Pavey *et al.* 2004, Lee and McCracken, 2004), or by the comparison of DNA fragments when appropriate species specific DNA markers are available (McCracken *et al.* 2004).

Due to the small size of the samples, all methods are tedious and have associated disadvantages including the required death of an animal for stomach content analysis, and the identification of only the indigestible parts in faecal matter analysis. Disadvantages of the last method include identification being often only to Order and sometimes to Family level, the high percentage of small particles remaining unidentified (35% Freeman Long *et al.* 1998), and previous absorption of soft-bodied organisms. The limited availability of appropriate DNA markers, and the time between sampling and testing are disadvantages of faecal analysis by DNA matching.

In 1998 the food sources for twenty two of the sixty five Australian microbat species listed by Churchill in 1998 were unknown (Table 1.4b). The food sources for the remaining 42 Australian species include a wide range of invertebrates, and are shown in Table 1.4b.

Table 1.4.b. Food source comparison for the six Australian microbat Families (Churchill 1998)

Family	**Nos. spp.**	**Number possible spp. in study area**	**moths**	**beetles**	**grass hoppers**	**bugs**	**flying ants**	**others**	**unknown**
Emballonuridae (sheathtail)	8	1	0 (2)	2m (2)	0 (3)	0 (3)	0 (3)	0 (2Q.)	4
Megadermatidae (large winged)	1	0	0 (1)	0 (1)	0	0	0 (1)	0 (1)	0
Rhinolophidae (horseshoe)	3	0	0 (2)	0 (2)	0 (1)	0 (1)	0	0 (1)	1
Hipposideridae (leafnosed)	7	0	2m (4)	0 (5)	0 (1)	0 (2)	0 (3)	0 (4)	1
Vespertilionidae (evening)	35	12 (2Q.)	6m (15)	3m (15)	0 (3)	1m(11)	0 (10)	3 (16)	12
Molossidae (freetail)	11	4	1m (4)	0 (5)	0 (2)	2m (4)	0 (3)	1m (3)	4
Totals	**65**	17(+2Q.)	**9m (28)**	**5m (30)**	**0 (10)**	**3m (21)**	**0 (20)**	**3+1m (1+24 +2Q.)**	**22**

KEY

Q.	questionable
no bracket:	number of species including the invertebrate category as a major component in diet;
m:	greater that 50% of diet
number in brackets:	number of species including the invertebrate category as prey component in range of prey categories.

Moths (Lepidoptera) and beetles (Coleoptera) appeared as major dietary percentages for 9 and 5 respectively of the sixty five microbat species (Table 1.4b). Although moths (particularly) and beetles appear as components of 28 and 30 species respectively of microbats with diverse diets, bugs (Hemiptera) contributed to the diets of 21 bat species, flying ants (Hymenoptera) to 20 bat species, and various combinations of other invertebrates (termites, flies, mosquitoes, wasps, crickets, cicaders, leafhoppers, caterpillars, ants, cockroaches, spiders, mayflies, cadisflies, and others) formed dietary components in varying proportions for at least 28 microbat species (Churchill 1998). Recent research in northern Australia (Pavey *et al.* 2004) also found diets dominated by moths and beetles with the addition of grasshoppers, but this study found no evidence of specialisation for the twenty microbat species investigated.

Results of surveys conducted in Victoria and Tasmania (Churchill 1998) for the same species of microbat demonstrated that dietary component percentages differed regionally. It would appear that many microbat species are opportunistic foragers taking what is locally abundant (Vestjens and Hall 1977, Freeman Long *et al.* 1998, McWilliams 2005, Lee and McCracken 2005). As food resource partitioning has also been observed (Whitaker 2004, Carter *et al.* 2004), both spatial and temporal variations in diets of microbats are to be expected (Lee and McCracken 2005, Bayefsky-Anand 2005). There are a small number of microbat species that do have more specialised diets, for example the predation upon fish and aquatic invertebrates by large footed myotis (*Myotis adversus*) (Campbell *et al.* 2004), and spiders by the golden-tipped bat (*Phoniscus papuensis*) (Law and Chidel, 2004). Very few studies have included seasonal or long-term temporal research.

Microbats and dietary consumption of cotton insect pests

Research has been conducted, predominantly outside the cotton industry, into microbat and moth predatory/prey relationships. Although not in Australian cotton fields, populations of millions of the cave dwelling mexican freetail bats (*Tadarida brasiliensis*) in Southern Texas, USA, have been observed feeding upon populations of billions of high-flying migratory pest insects (McCracken 1999, McCracken & Westbrook 2002, McCracken *et al*. 2004). Insect populations included a high percentage of the cotton bollworm moth (*Helicoverpa zea*) one of the most destructive pests of field and row cropping in the USA and closely related to the *Helicoverpa* spp. pests of Australian grown cotton. Dietary analysis of microbat faeces demonstrated a two to three fold increase in moth consumption correlated with migration schedules and availability to the bats of migratory populations of adult bollworms (McCracken *et al.* 2004). Moth consumption decreased when crops senesced and moth populations had declined (Lee and McCracken 2005). McCracken *et al.* (2004) calculated that a 12gm bat eating 8gm of moths each night equated to approximately 5,000 tons of insects consumed by 1 million bats per night. Although caves are not present in the immediate research area for this project and microbat numbers are reduced, predation of high flying migrating moths by microbats is likely to be occurring, to a lesser degree.

Differences in reported estimations of food consumption to percentage of body weight per bat from 66% (McCracken *et al.* 2004) to >70% (Kunz *et al.* 1995b) could be attributed not only to prey availability but also to seasonal and intraspecific biological differences in energy requirements and consequent food consumption eg. increased food consumption during gestation and lactation (Kunz 1974, Kunz and Stern 1995, Lumsden *et al*. 2002a).

Analysis of faeces collected from microbats foraging on agricultural crops in California, USA, showed that predation was opportunistic and varied with changes in insect abundance, but included predation upon many agricultural pest species (Freeman Long *et al.* 1998, & Freeman Long 2001). Microbats in Victoria predated upon Rutherglen bugs, serious pests of sunflower, safflower, fruit and vegetable production (Lumsden 1993). These bugs comprised 80% of the little freetail bat (*Mormopterus planiceps*) diet.

As many microbat species are opportunistic predators, and some species glean from foliage (Rydell 1998, Ratcliffe and Dawson 2003), increased populations of previously secondary pests (mite, aphid, mirid and thrip) accompanying the wide-scale introduction of Bollgard II™ although small could possibly be prey for microbats in Australain cotton fields (Lee and McCracken 2005). Mirids appeared as a dietary component in the Lee & McCracken comparative analysis. Because they are mobile, microbats have been shown not only to be opportunistic predators, but also able to maximise their average rate of food intake by balancing habitat selection (Arlettaz 1996).

Microbats and cotton insect pests as ultrasound echolocation prey targets

Ultrasound echolocation used by microbats is an acoustic imaging system (Simmons and Stein 1980) providing microbats with information about the size, composition, direction, speed and movement of a prey source or other object (Simmons and Stein 1980, Churchill 1998, de Oliveira 1998). Individual bat species use different ultrasound frequency ranges and call constructions (Habersetzer and Volger 1983, Waters and Jones 1995, Kalko 1995, Fenton *et al*. 1998, de Oliviera 1998, Reinhold *et al.* 2001, Simmons *et al.* 2001, and Pennay *et al.* 2004). Some microbat species augment these techniques with hearing and sight (Churchill 1998, Eklof and Jones 2003, Phillips 2003).

Over 14 families of moths including noctuid moths such as the cotton pest *Helicoverpa* spp. (Waters 2003), along with many other insect species (Libersat and Hoy 1991, Lakes-Harlan and Heller 1992, Forrest *et al.* 1995, Faure and Hoy 2000), have auditory systems sensitive to most microbat ultrasound echolocation ranges (Roeder and Treat 1961, Spangler 1988, Hoy and Robert 1996, Fitt and Boyan 2000). At the detection of an approaching microbat many insect species with hearing ability adopt avoidance behaviour (Roeder and Treat 1961, Treat 1962, Belton and Kempster 1962, Roeder 1962, Roeder 1964, Agee 1969, Agee and Webb 1969, Spangler 1988, Fullard *et al.* 2003, Grieg and Greenfield 2004, Guignion and Fullard 2004, Soutar and Fullard 2004). On hearing an approaching microbat moths increase flight speed, adopt multidirectional flight, or dive into foliage to avoid capture (Roeder 1962/64, Rydell *et al.* 1995, Waters and Jones 1996, Acharya and McNeil 1998, Jones and Waters 2000). It could be projected that these avoidance activities are causing extensive interference to cotton pest moth nightly reproductive activities (Steins *et al.* 2003, Dillon *et al.* 2004, Greig and Greenfield 2004, Svensson *et al*. 2004).

Microbat foraging activities could therefore be a significant component of insect pest management in cotton production contributing to reductions in pest populations in two ways: (i) by direct predation, and, (ii) by ultrasound echolocation avoidance resulting in interference with pest mating and egg-lay reproductive activities (Dillon *et al*. 2004, Greig and Greenfield 2004). Observations across Narrabri cotton fields prior to this research project (Dillon *et al.* 2004) revealed the occurrence of microbat presence and moth avoidance behaviour (Dillon, MacKinnon and Freeman Long unpublished, Steines *et al.* 2003). Thus, the presence of microbats could be providing a very important ecosystem service to cotton production.

Microbats and vegetation remnants on cotton properties

Microbats and roosting sites

Little is known of roosting preference and selection for many microbats species. An examination of the known roost preferences (Churchill 1998) for the 65 microbat species recorded in Australia (Table 1.4c), indicated some similarities in Family preference.

Fourteen of the nineteen microbat species belonging to the Families Emballonuridae, Megadermatidae, Rhinolophidae and Hipposideridae roost in caves or cave like structures either exclusively or predominantly (all located in northern Australia) with only two species roosting predominantly in tree hollows. Of the remaining species, two use a variety of roost sites and the roost selection for one species is unknown.

Table 1.4.c. A comparison of roost site selection for the six Australian microbat Families (Churchill 1998)

Microbat Family	No. of species	No. of spp. in study	Cave	Cave like structures	Tree hollows	Trees – other parts	Bark	Man-made structures	Other specific
Emballonuridae (sheathtail)	8	1	4	1	2 (1)	0	0 (1)	0	0 (1)
Megadermatidaee (large winged)	1	0	0	1	0	0	0	0	0
Rhinolophidae (horseshoe)	3	0	0 (1)	2	0 (1Q.)	0 (1Q.)	0	0	0
Hipposideridae (leafnosed)	7	0	0 (1)	6	0 (1)	0	0	0 (1)	0 (1)
Vespertilionidae (evening)	35	12 +2Q.	2 (8)	1 (8)	5 (16)	1+1Q. (6)	0 (6)	0 (10)	4 (3)
Molossidae (freetail)	11	4	0 (2)	0	3+1Q., (7)	0 (1)	0	0 (6)	0 (2)
Total	**65**	**17 +2Q.**	**6 (12)**	**11 (8)**	**10+1Q.. (25+1Q.)**	**1+1Q. (7+1Q.)**	**0 (7)**	**0 (17)**	**4 (7)**

KEY

Q.	questionable
no bracket:	number of species using this roost selection solely;
number in brackets:	number of species using this roost selection as component in range of roost categories.

On the other hand the forty-six species belonging to the Vespertillionidae and Molosidae Familites utilise a greater diversity of roost sites, only two roost in caves or cave like structures exclusively. Although only nine of these species roost in tree hollows exclusively, twenty-three others utilise tree hollows together with a diversity of alternate sites. Thus 70% of species belonging to these two Familes use tree hollows. Seven species include other components of trees in their roost selection (eg. foliage) and six include roosts under bark. Sixteen species have been able to adapt and utilise man-made structures in their repertoire of alternate roost sites. It is known that four species select very specific roost sites eg. golden tipped bats (*Phoniscus papuensis*) utilised abandoned moss and lichen nests in vines in rainforests or wet sclerophyll forests made by gerygones and scrubwrens (Schulz 1995), and flute-nosed bats (*Murina florium*) roost in ferns along the northern Queensland coast (Spencer and Flemming 1989). The roost sites for the hairy nosed freetail (*Mormopterus* sp. 6) are unknown. (Churchill 1998).

Native vegetation remnants in the research area include stands of river red gum (*Eucalyptus camendulensis*), poplar box (*E. populnea*), grey box (*E. pilligaensis*) all containing tree hollows, as well as stands of iron bark (*E. melanophloia*) and cypress pine

(*Callitris glaucophylla*) both of which could provide trunks of thick bark for roosting sites.

Microbat species roost selection in agricultural landscapes

Spatial analysis of foraging and tree hollow selection for four Australian bat species, one in a NSW eastern coastal forest, two in a Victorian grazing system (one of these was also studied on the New England Tablelands) and one on Phillip Island in Victoria, indicated specific roost selection requirements (Law and Anderson 2000, Lumsden and Bennett 2000, and Lumsden *et al.* 2002a and b, Turbill *et al.* 2003b, Campbell *et al.* 2005).

Tree hollow roosting site selection by microbats varies both intraspecifically and interspecifically. In a Victorian grazing system and climatic conditions *Chalinolobus gouldii* selected roost sites in dead limbs of river red gums (*E. camaldulensis*), and *Nyctophilus geoffroyi* selected sites almost exclusively in dead trees (Lumsden *et al.* 2002a), whilst on the New England Tablelands *N. geoffroyi* roosted under bark mainly of ribbon gums and dead acacias (Turbill *et al.* 2003b). *Vespadelus vulturnus* on Phillip Island roosted in dead timber predominantly in decayed remains of eucalypt trees as well as dead sections of live trees (Campbell *et al.* 2005).

Small body size and thermoregulation were suggested possible reasons for intraspecific variation (Law and Anderson 2000, in Law and Anderson 2000, Hosken 1996, Vonhof and Barclay 1997, Turbill *et al.* 2003a/b, Turbill 2006a/b). The height, size and aspect of the tree trunk or of the hollow entrance, the internal size of the hollow, and density of trees with appropriate hollows, and lack of foliage near entrances were all important factors in seasonal selection variation. Distances traveled between foraging and roost sites also varied seasonally, interspecifically and intraspecifically, with females of one species traveling up to 12 km. several times a night to feed young (Lumsden *et al.* 2002a). Little roost selection research has been conducted for many Australian bat species.

Tree hollows

Tree hollow formation and tree hollow category type selection by Australian fauna has been reported in Gibbons and Lindenmayer (2002), and Gibbons *et al.* (2000). Eucalypts develop hollows as early as 35 years of age, but commonly only after 150-180 years, with large hollows rare under 220 years (Gibbons and Lindenmayer 2002). The propensity of eucalypts to form hollows differs between tree species. Tree hollow development requires three essential preconditions: (i) physiological stress or physical injury; (ii) presence of heartwood decay; and, (iii) a tree of sufficient size to persist when decayed. Given favourable moisture, high productivity areas support more trees with hollows (Gibbons & Lindenmayer 2002). The very old native vegetation remnants within the research area could offer an extensive range and number of tree hollows for roosting sites.

1.5 CONCLUSIONS

This review has outlined the interrelating social, political and economic factors pertaining to an investigation of microbats in an Australian cotton production landscape at the commencement of the 21st century. The survival of microbats in such a landscape settingwill depend upon the flexibility of the bat community and its individual species. The repertoire of strategies enabling microbats to be successful is dependant upon their biology and their adaptability to living with and utilising the human landscape. This is the context of the following study.

CHAPTER 2   PROJECT AIMS

Contents

2.1 AIMS

The aim of this research project was to examine the links between microbats, cotton production and vegetation remnants.   Located between Narrabri and Wee Waa, adjacent to the Namoi River on the north west plains of NSW, it set out to identify the composition and diversity of a microbat community across a cotton production landscape as an example of biological diversity and ecosystem function in a extensively altered agricultural landscape. It sought to identify variability in microbat landscape utilisation, its relationship to habitat composition and structure, including the role and function of the landscape elements associated with cotton production.

Based on the project findings, an extensive literature review, and an evaluation of insect pest problems and past management approaches, the project objective was to establish potential for the use of microbats as a conservation tool for the future. It was hoped that a cotton production value derived from a scientific study examining cotton related microbat activity would provide new incentives for improved management of declining remnants of indigenous woodland as microbat roosting habitat.

2.2 BACKGROUND

It became apparent that if this project was to provide incentives for changes in native vegetation management, an understanding of themotivations for historic agricultural management practices was required. The perception that landscape degradation is directly attributable to historic agricultural practices is wide spread in both academic and grey literature (Dickman 1994, Goldney and Bauer 1998, 2000, Bergman and Lindenmayer 1998) and underpins much policy formulation and community sentiment. Such assumptions associated with past land management and more recently cotton production . are accompanied by a culture of blame and resultant research focused on legislative solutions for vegetation management.

The NSW State Environmental Planning Policy No 46 (SEPP 46) and the complicated Native Vegetation Conservation Act 1997, resulted in landowner mistrust, cynicism, often resistance, and in all arenas residual "them" and "us" viewpoints persisting into more recent vegetation management planning and legislation.

The Native Vegetation Act 2003 addressed many issues. More recent changes in understanding of past devastating environmental impacts have facilitated a widespread stakeholder relaxation in attitude and a willingness to contemplate better land management practices. Despite such changes, a general reluctance primarily from policy makers and researchers to embrace a new paradigm has manifested in an impasse. Landholders have been locked into positions of seemingly little choice - disempowered from seeking their own solutions, but with perceptions that conservation is a threat to their pride and existence rather than an opportunity. It is therefore desirable that recommendations for change in native vegetation management as outcomes of this project are based upon an understanding of past land management events in the research area, as well as the motivations and ramifications of those events.

Framework for the study

The context of this project and its implications for vegetation management therefore necessitated an investigation of the following two assumptions (Old body of thought Fig. 2):

1. *present landscape condition* is attributable to past land management practices which were based on the desire to subdue and conquer and to create 'useful' landscapes, resulting in land degredation.

2. *present biodiversity condition* is attributable to past cotton productionexploitation of land for profit including extensive utilisation of pesticides and water, resulting in massive habitat destruction and biodiversity extinction.

With little historical investigation into landscape change previously undertaken within the research area, and an almost complete absence of microbat research in cotton landscapes to provide historical baseline data, could these assumptions be regarded as constructs? Have the results of research conducted at other locations and in other situations been extrapolated at too broad a scale, resulting in constructions of past events for the study area?

The interrelationships between the assumptions outlined above, their current context, future impacts and implications and their incorporation into the research project are illustrated in Fig. 2.

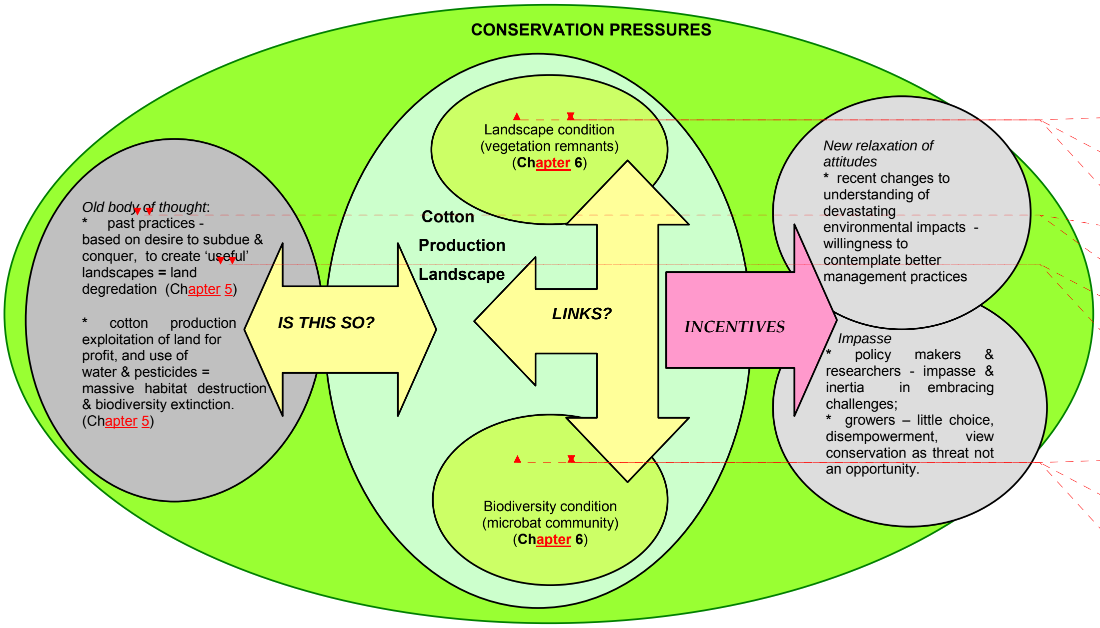

Fig. 2 Concepts and their relationships for the research project.

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Research approach

From the outset, this project avoided an authoritative researcher focus but instead adopted a semi-participatory approach akin action research (Greenwood *et al.* 1981). It was hoped this approach would lead to greater mutual researcher and landowner understanding, and greater landowner ownership, subsequent adoption and commitment to any project outcomes and recommendations.

Because of the funding nature of the project, throughout the project opportunities have been taken to share research findings within the cotton industry. These opportunities have been: with the participating growers, at management field days, workshops, Australian Cotton CRC conferences and reviews, Australian Cotton Research and

Development Corporation forums and conferences, an Australian Cotton Conference, as well as Land and Water Australia conferences, field days and postgraduate forums.

As a result of the project approach the three landowners involved in the study became the study's greatest advocates. The hoped-for more extensive landowner uptake of project outcomes was recently facilitated by employment of the researcher by the Border Rivers-Gwydir Catchment Management Authority to extend the project outcomes across the Moree plains area of the BR-G CMA.

2.3 QUESTIONS

The following questions investigate the historic assumptions as possible constructions in the study area. The results provide both important baseline data and benchmarks within the rapidly changing cotton industry.

Question 1. Cotton landscape – a historical reconstruction

As microbats are predominantly insectivorous and in the study area dependent primarily upon tree hollows for roosting sites, what historic landscape changes have occurred that may have impacted upon microbat communities?

Question 2. Microbat presence and community structure

If microbats are highly dependent upon a diversity of both insect prey fauna and tree hollow roosting sites, is there a microbat presence across a cotton production landscape and if present what is the current presence and diversity?

Question 3. Microbat utilisation of the natural versus the human cotton production landscape

In a cotton production landscape comprised of both remnants of indigenous vegetation differing in composition and density, and agricultural fields of irrigated, dryland cropping and fallow differing in composition seasonally, how does a microbat community and its individual species utilise the cotton production landscape both spatially and temporally?

Supplementary Question

Question 4. Identification of variables affecting microbat presence in the cotton landscape

What are the variables that impact upon the presence of microbats across the cotton production landscape?

CHAPTER 3 THE STUDY SITE

Contents

3.1 LANDSCAPE SCALE STUDY AREA

Currently in Australia there are fourteen cotton growing areas (Fig. 3a) spread across New South Wales and Queensland, predominantly within the Murray Darling basin. The research area (red square in Fig. 3a) is located in Australia's longest established cotton growing area along the Namoi River, between Narrabri and Wee Waa. It is within the Darling Riverine Plains subregion of NSW.

Fig. 3.a. Cotton growing areas in NSW and Queensland (CRDC 2003).
The research area in the lower Namoi catchment, west of Narrabri, is marked by a red square.

The 56km² study area (Plate 3a) is bordered to the north and north-east by the Namoi River, the east by Bohena Creek, the south by the Narrabri/Wee Waa railway, and the west by Wild Willows Road. It extends across three adjacent and interlinked cotton production properties, two of which are operated as mixed enterprise family businesses.

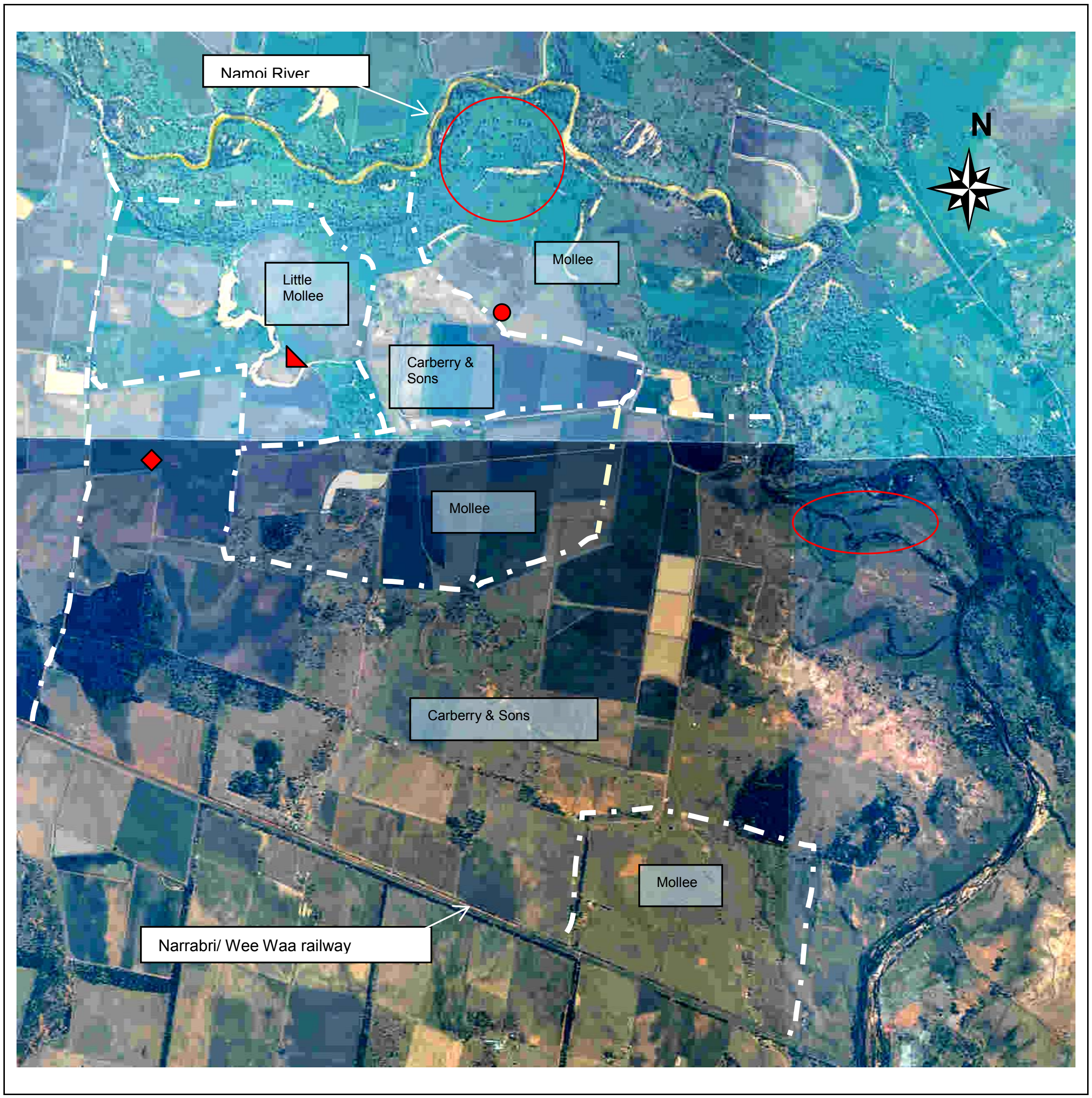


Plate 3.a. 2003 Aerial photograph (Land and Property Information 2003) of the three properties subject of the research area, bordered to the north- and north-east by the Namoi River, the east by Bohena Creek, the south by the Narrabri/Wee Waa railway, and the west by Wild Willows Road. (Red markers are sites of photographic Plates 3b, 3c and 3d below; red circling indicates areas of lippia remediation Plates 3e and 3f below)

The percentages of income return of 80% from irrigated cropping, 13% from dryland cropping and 7% from cattle grazing, (Table 3a) for the larger property "Carberry & Sons" (Plate 3d) are not representative of the percentage of land utilised for these enterprises. Large proportions of this property are devoted to cattle production supported by feed-lot practices and dryland crop production.

The second family enterprise (Plate 3b) receives 60% of income return from irrigated cropping and 20% each from dryland cropping and cattle grazing. Cattle production for this property includes supplementary feeding on dryland stubble and grain. Furrow flood irrigation is used for irrigated cropping production on both properties.

Table 3.a. Percentage Income return attributed to landscape elements

Property	Native vegetation	Intensive Management	
	grazing	irrigated cropping	dryland cropping
1 Carberry & Sons	7#	80*	13
2 Mollee	20+	60	20
3 Little Mollee	unavailable	unavailable	unavailable

KEY
* includes cotton seed
\# includes grazing on dryland stubble
\+ includes supplementary feed – dryland stubble and grain
Note Property 3 is a commercial cotton variety seed producer

The third property (Plate 3c), utilising overhead pivots and traveler spray irrigation, is owned by a commercial cotton seed company concentrating on commercial cotton variety seed production for the industry. The manager, who also managed for the previous owners, conducts a small supplementary cattle production enterprise. Cattle are grazed within vegetation remnants on all properties except within lippia (*Phyla canenscens*) infested river red gum woodlands (Plates 4.Ai and 4Aii Attachment 4).

Plate 3.b. "Mollee" Summer 2004 (filled red circle Plate 3a); river red gum forest in background – LtoR – fallow dryland cropping, poplar box, lucerne fodder cropping, water supply channel, and furrow irrigated cotton.

Plate 3.c. "Little Mollee" Autumn 2004 (red triangle Plate 3a) – LtoR – overhead traveler irrigated defoliated cotton ready for pickiing & in the background river red gum open woodland, edge of circular field, poplar box open woodland, grassland & isolated trees (upper Deadman's Creek catchment).

Plate 3.d. "Carberry and Sons" Autumn 2004 (red diamond Plate 3a) – LtoR picked cotton & in background poplar box open woodland and Mt Kaputar & Nandewar Range, roadway, furrow irrigated cotton defoliated and ready for picking & in background mixed species and cypress pine remnants

3.2 CLIMATE

The Narrabri Wee Waa area typically has hot summers with average minimum and maximum temperatures of 17ºC and 35ºC, often reaching above 40ºC, and in winter warm days and cold nights with average minimum and maximum temperatures of 3ºC and 17ºC. Frosts are recorded each winter. Snow has been recorded to the east, at the top of Mt. Kaputar 1,524 metres a.s.l. and along the Nandewar Ranges. The average annual rainfall is 635 mm. periodic flood events of the Namoi River occur.

3.3 GEOGRAPHY AND SOILS

The research area extends south from the Namoi River for approximately 10km traversing flood plain in the north and old river systems to sandy ridges in the south. The only three soil tests within the research area cited on Department of Land & Water Conservation website recorded prairie soil and brown clay on the upper flood plain of "Mollee" and "Cadarga", and red chromosol/red-brown earth on the roadside adjacent to "Cadarga" between the sandy ridges in the south (Table 3b).

Table 3.b. Three soil tests in the research area (dlwc.nsw.gov.au:8080/salis/servlet/SoilEssential)

Site	**Soil type**	**Description**
Mollee Long. 149.664435;Lat 30.241847 elevation 202m.	Prairie soil (GSG) Ug5.17(PPF)	Parent rock: alluvial sediment, mixed texture, non-calcareous, clay floodplain (silty clay with moderate peadlity to clay with moderate/weak pedality)
Cadarga 1985 Long. 149.636415; Lat. 30242865	Brown clay (GSG) Ug5.15(PPF)	Parent rock: alluvial sediment, clay floodplain (clay with moderate pedality)
Opposite Tunstal near railway 2001 Long. 149.620099; Lat. 30.293846	Red Chromosol (ASC) Red-brown Earth (GSG	Bown loam/clay to red clay – (with weak pedality)

Both the “Mollee” and “Cadarga” sites are at the junction between dryland and irrigated cropping areas and the “Tunstal” site is utilised for dryland cropping and grazing.

3.4 VEGETATION TODAY

Whilst all three properties have retained river red gum (*Eucalyptus camaldulensis*) and poplar box (*E. populnea*) woodland remnants, both family properties have also retained a variety of vegetation remnants. Lippia (*Phyla canenscens*) has invaded large areas of flood plain country across the three properties (Plates 3e and 3f), and cropping remediation programmes were commenced during summer 2003 on Mollee and summer 2004 on Cardale in the areas circled in red (Plate 3a).

Plate 3.e. “Mollee” summer 2004 LtoR Lippia remediation & river red gum open woodland (circled red Plat 3a), with river red gum forest in background, a bioremediation dam to catch runoff from cotton fields, Lippia infestation green in the foreground (Site Bi)

Plate 3.f. “Mollee” summer 2004 Second year lippia remediation programme of river red gum open woodland (circled red Plate 3a), between sorghum and barley cropping (Site Bd)

Today the remaining native vegetation remnants are very old and many trees are showing signs of senescence. A narrow forest or woodland corridor of a predominantly river red gum (*Eucalyptus camaldulensis*) community with isolated river-oak (*Cassuarina cunninghamiana*) and very isolated angophora (*Angophora floribunda*) adjoins the river on the lower flood plain. Across the upper flood plain an open woodland river red gum (*E. camaldulensis*) community predominates with isolated small stands of carbeen (*E. tessellaris*) and collibah (*E. coolabah*).

The intermediary soils between the flood plain and sandy soils to the south retain either communities of poplar box (*E. populnea*), grey box (*E. pilligaensis*) or mixed box communities that include grey box (*E. pilligaensis*), poplar box (*E. populnea*), belah (*Casuarina crista*) and some black wattle (*Acacia excelsa*).

The lighter soils to the south support predominantly cypress pine (*Callitris glaucophyll*) forest associations, with some eucalypt and box species (grey box (*E. pilligaensis*), silver–leafed ironbark (*E. melanophloia*) and/or Baradine or dirty gum (*E. chorodada*)) where the forest merges into woodland. Many of these areas have an understorey of thick cypress pine regrowth. A few of the latter communities are the only remnants containing a shrubby understorey, the composition of which is predominantly boonery (*Alectryon oleifolius*), wilga (*Geijera parviflora*), butter bush (*Pittosporum phylliraeoides*) or budda (*Eremophila mitchelli*). Areas of open grasslands often include isolated wilga (*Geijera parviflora*). Examples of all these communities are included in Attachment 4 below.

3.5 CONCLUSIONS

This current picture of the landscape has not happened overnight. It is the outcome of some 150 years of change since European settlement. Chapter 5 will reconstruct the history of the current landscape. Only a better understanding of this history will enable us to understand the current landscape and project its future.

CHAPTER 4   METHODOLOGY

Drawing patterns across the landscape

Listening as calls are recorded and writing nocturnal observations.
Weather station, data logger, battery pack and compass in foreground are connected to the Anabat bat recorder at the edge of darkness.   (Photograph J. Bauer)

CONTENTS

INTRODUCTION

An historical reconstruction of the study area landscape was undertaken to understand changes in agricultural production practices and their motivation as well as changes in microbat habitat. In order to sample microbat activity and diversity across the cotton landscape an appropriate research design was developed which captured both landscape and habitat scale. The size of the study area selected was 53 km² within which sampling sites were distributed through a step-wise random stratification design. Seven indigenous vegetation community types and three differing intensive management types were identified and sampled modified by feasibility considerations, for microbat activity. A variety of methods were applied to address the research questions.

4.1 LANDSCAPE RECONSTRUCTION

In order to understand the landscape changes determined by agricultural production practices and motivation and capture changes to possible microbat habitat as a consequence of these human activities, this study commences with a historical reconstruction of the landscape changes in the study area.

A desktop survey was conducted utilising the following sources:

I. Surveyor's notes on the available Portion Plans of the Parish of Mollee, County of White, Land District of Narrabri New South Wales, between 1895 and 1926, from NSW Department of Lands, Moree (Table 4.2a); and
II. aerial photographs purchased from the Land & Property Information, Bathurst for the years 1962, 1972, 1998 and 2003 (Table 4.2a).

Table 4.1.a. Portions Plans and aerial photographs used in the examination of historical landscape changes

Date	Reference	Source
Portion Plans, Parish of Mollee, County of White, Land District of Narrabri, NSW.		
1895	Plans of Portion 48	NSW Department of Lands, Moree
1901	Plans of Portion 60	NSW Department of Lands, Moree
1901	Plans of Portion 49	NSW Department of Lands, Moree
1904	Plans of Portion 27	NSW Department of Lands, Moree
1904	Plans of Portion 28	NSW Department of Lands, Moree
1913	Plans of Portion 66	NSW Department of Lands, Moree
1915	Plans of Portion 67	NSW Department of Lands, Moree
1926	Plans of Portion 51	NSW Department of Lands, Moree
1926	Plans of Portion 58	NSW Department of Lands, Moree
Aerial photographs		
1962	NSW 1164	Land and Property Information, Bathurst
5.11.1972	NSW 2106 5178	Land and Property Information, Bathurst
10.07.1998	Run 4 101-113; Run 5 01-14	Land and Property Information, Bathurst
18.07.2003	Runs 4 203, 205; Run 5 152, 153	Land and Property Information, Bathurst

Interviews were conducted with either current or previous landowners or managers who were identified as appropriate to represent the oral history of the landscape changes in the research area between 1919 and the present day. Although answers were sought to specific questions about events and the event drivers, care was taken to conduct these interviews in an inclusive conversational manner without any interrogation. The time-span and the properties represented in the landowner interviews are set out in Table 4.2b.

Table 4.1.b. Time-frames and properties represented by landowner stories

Period	**Property**	**Interviewee**	**Spokesperson for**
1919 to present	Cadarga	Pat Carberry	Father, himself, brother, son and nephew
1926 to 1974	Mollee	Jerry Killen	Father, himself and brothers
1930 to present	Nyalla	Pat Carberry	Father, himself, brother, son and nephew
1950 to present	Cardale	Pat Carberry	Father, himself, brother, son and nephew
1974 Mollee subdivided and sold			
1974 to present	Wilga & Green Trees	Pat Carberry	Father, himself, brother, son and nephew
1974 to present	Mollee	Phil Norrie	Father, uncle and himself
1974 to present	Little Mollee	Alan Goode	Previous owner, himself and new owner

There are presently three enterprises in the study area. ‘Cadarga’, ‘Nyalla’, ‘Cardale’, ‘Wilga’ and ‘Green Trees’ are incorporated into S. Carberry & Sons and are referred to in this study as the ‘Carberry Enterprise’ or ‘Carberry & Sons’. The remaining portions of the original ‘Mollee’ property, ‘Mollee’ is owned by the Norrie family, and ‘Little Mollee’ is owned by Cotton Seed Distributors and managed by Alan Goode.

The descriptions of vegetation made by surveyors on the Portion Plans between 1895 and 1926 were combined on a single map and used in comparisons of present day vegetation (Fig. 5.A). Information gained from the transcribed interviews was juxtaposed against changes visible in the aerial photographs between 1962 and 2003. The landscape changes and their drivers were identified and the status of native vegetative cover coded in order of visibility across today’s landscape.

4.2 RESEARCH DESIGN RATIONALE

A principal objective of this research project was to investigate any microbat presence and its contribution to cotton pest management. Hence the monitoring of microbat activity over cotton fields at various stages during cotton production was an essential component of the research design. Autumn defoliation and picking of cotton crops (Plate 4.2b) result in much reduced insect and therefore microbat foraging habitat. Consequently autumn sampling of microbat activity over cotton fields after cotton had been defoliated and picked acted as a design 'control' within a comparative seasonal assessment of microbat activity during the 2003/04 growing season (Plate 4.2a).

Plate 4.2.a. Site Hb (IC) irrigated cropping in Summer – "Mollee" & "Cardale" ("Mollee" crop left in process of irrigation)

Plate 4.2.b. Site Hb (IC) irrigated cropping in Autumn after defoliation and picking - "Mollee" & "Cardale"

The second principal objective was to investigate the microbat utilisation, and therefore the habitat value and landscape function, of differing indigenous vegetation remnants across a cotton production landscape. A research design was required to accommodate both of these objectives.

4.3 PLANNING

Identification of landscape habitat types

Ten different landscape habitat types, seven native vegetation and three intensive management, were identified across the research area and are set out in Table 4.3 and Fig. 4.3a and in Attachment 4. Throughout this document, with the exception of dryland cropping (DC) the landscape categories are ordered to represent their proximity to the river (Fig. 4.3a). Although some dryland cropping is undertaken asjacent to the river most is undertaken in the higher southern areas of the study area..

Table 4.3. Landscape habitat categories identified across the study area

	ID	Category	Description
Native vegetation categories	**RGF (A)**	river red gum (*Eucalyptus camaldulensis*) associations, with isolated angophora (*Angophora floribunda*), or river sheoak (*Cassuarina cunninghamiana*)	grazed forest/woodland adjacent to the river
	RGOW (B)	river red gum (*E. camaldulensis*) associations – individuals or small stands of carbeen (*E. tessellaris*) or coolibah (*E. coolabah*);	grazed open woodland/scattered trees – immediate flood plain (In 2003 41% cropped for lippia management)
	PB (C)	poplar box (*E. populnea*)	grazed woodland & open woodland patches and corridors – higher flood plain, old water courses,
	GB (D)	Pillaga grey box (*E. pilligaensis*)	
	MIX (E)	mixed species – poplar box (*E. populnea*), Pillaga grey box (*E. pilligaensis*), belah (*Casuarina crista*), and black wattle (*Acacia excelsa*)	grazed mixed spp. woodlands –sparse to medium densities of bushy understorey; intermediary soils between flood plain and sandy ridges - roadways, fencelines
	CP (F)	cypress pine (*Callitris glaucophylla*) associations	dense stands – including belah (*Casuarina cristata*) silver–leafed ironbark (*E. melanophloia*) and/or Baradine or dirty gum (*E. chorodada*) & bushy understorey
	GIT (G)	grassland some isolated trees often wilga (*Geijera parviflora*)	grazing (In 2004 15% cropped for lippia management)
Intensive manage-ment categories	**IC (H)**	irrigated cropping	cotton/wheat/fallow rotational cropping – sometimes includes legumes
	WS (I)	water storage	varying in size, as well as depth and water level, construction and vegetative surrounds
	DC (J)	dryland cropping	wheat, and cropping for grazing eg. lucerne, legumes

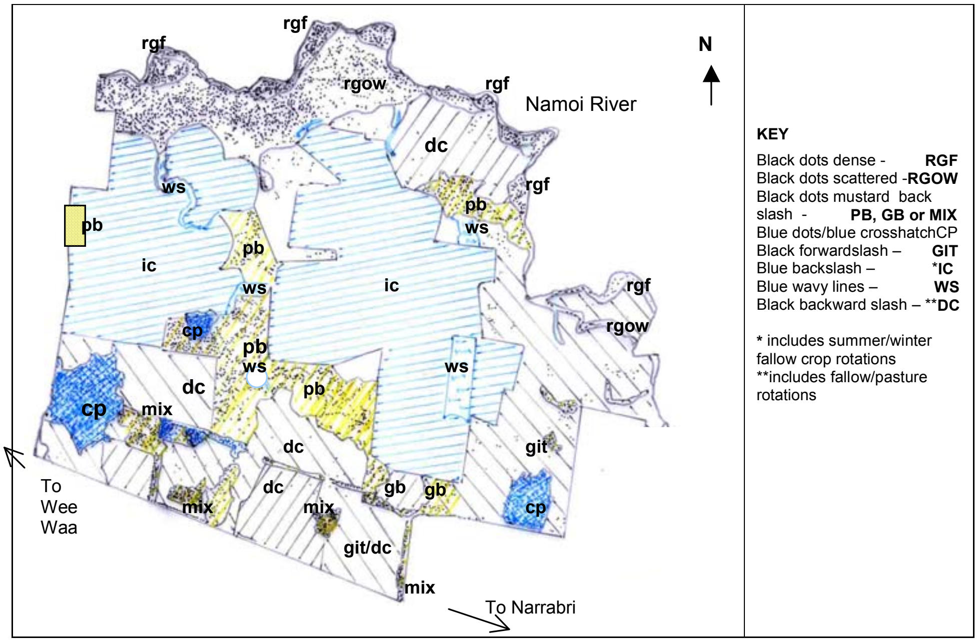


Fig. 4.3.a. Research area divided by native vegetation and intensive management landscape categories

Proportional representation of landscape types in the study area

The proportional percentages of land associated with native vegetation and intensive management in 2003 within the study area are illustrated in Figs. 4.3b & 4.3c. Utilisation of the intensive management categories varies seasonally depending upon climatic conditions, rotational management systems and commodity prices.

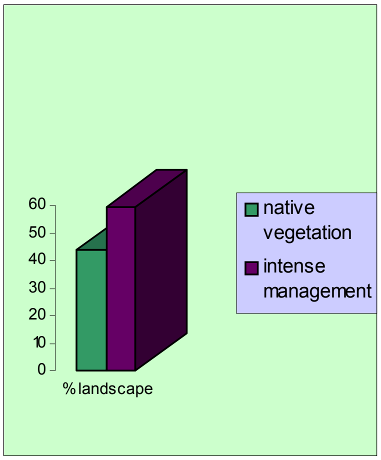


Fig. 4.3.b. Percentage of native vegetation compared with intensive management landscape categories in the study area

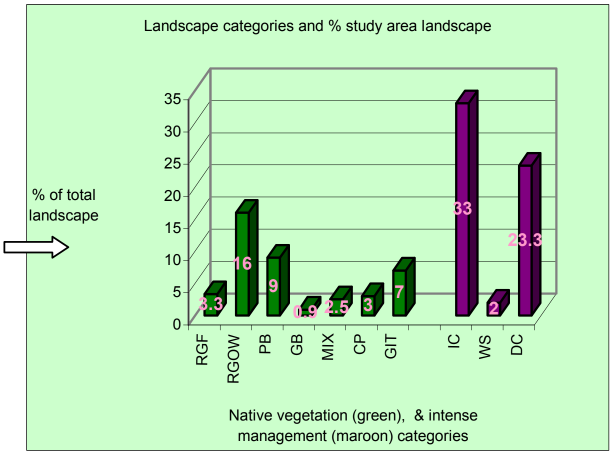


Fig. 4.3.c. Percentage of total research area landscaperepresented by each landscape category– both groups ordered L to R in approximation to the river.

Of the total research area, the 58.3% utilised for intensive agriculture is divided by three management categories, (IC) irrigated cropping 33%, (DC) dryland cropping 23.3%, and (WS) water storages 2%. The remaining 41.7% of the research area is comprised of seven indigenous native vegetation types, (RGOW) river gum open woodland 16%, (PB) poplar box 9%, (GIT) grasslands and isolated trees 7%, (RGF) river gum forest 3.3%, (CP) cypress pine dominated communities 3%, (MIX) mixed species remnants 2.5%, and (GB) grey box remnants 0.9%. At varying intensities, vegetation remnants and dryland cropping areas are utilised for cattle production.

Field sampling techniques

Techniques available for sampling microbats for both recording calls and capture have been revolutionised during the past 15 years and are still being significantly improved. The methodologies selected for this project reflect the constraints imposed by changing technologies, and feasibility and expense. The sampling techniques selected were:

i. Recording and analysing microbat ultrasound echolocation calls using an Anabat II bat recorder with a CF Storage ZCA Interface Module and Compact Flash Memory Card (Titley Electronics Pty. Ltd.), and Analook computer software (Corben and O’Farrell 1999 and Titley Electronics Pty Ltd.) to facilitate species identification and examination of patterns of activity and distribution across the landscape (Plate 4.3a, c & d).

Although acoustic equipment for recording microbats has been available for over thirty years, technologies have advanced rapidly in recent years. The Anabat II Bat Detector (Titley Electronics Pty. Ltd.) is a broadband recorder that converts ultrasonic signals into audible electronic signals using Zero Crossing Analysis (ZCA) (Titley Electronics Pty. Ltd.). It is part of a system that has advanced from recording calls using cassette tapes, delay switches and timers, to laptops, batteries and cables in the field, to recorded calls stamped with time, date and GPS location stored via a CF Storage ZCA Interface Module onto a Compact Flash Memory Card that can be downloaded into a computer for later analysis. Recent innovations include a PDA based system attached to the bat detector providing real-time Anabat displays (Corben 2006) enabling calls to be heard and seen whilst walking around in the field, thus facilitating immediate identification.

Analook (Corben and O'Farrell 1999 and Titley Electronics Pty. Ltd.) computer analysis software converts recorded calls into individually displayed calls accompanied by a suite of measurement capabilities. This software has very recently been converted from a DOS based programme to one compatible with XP for Windows. Other recent innovations include AnaScheme (Gibson and Lumsden 2003) an automated bat call identification system that facilitates the processing and identification of large numbers of calls against a set of introduced regional individual species call parameters using regression analysis.

ii. Capturing microbats using harp traps (Faunatech/Austbat Research Equipment) to facilitate: species identification, verification of identifications made with Anabat technologies, collection of biological data, and the recording of calls on release. The harp traps were loaned from New South Wales Department of Environment and Conservation (Narrabri, Coonabarabran and Dubbo) and the Faculty of Rural Management, University of Sydney, Orange (Plate 4.3e & f).

The range of microbat capture devices includes hand nets, mist nets, harp traps and trip lines. Many capture devises require the removal of bats immediately after capture. As harp traps contain a holding bag they can be set during the day and either checked during the night if sampling when lactating females are likely to be captured, or left until dawn to retrieve captured bats held in the bag. Harp trap design has also been regularly improving (Gration 2003, 2004, 2006).

The combination of call recording and trap capture allowed compensations for the inadequacies of each method (Duffy *et al.* 2000). The echolocation of some species is difficult to record and identify, and other species are difficult to capture in traps.

Ultrasound recording equipment and field sampling system – EA03 and SSA03/04 surveys

Plate 4.3.a. Anabat II bat recorder and CF Storage ZCA Interface Module (Titley Electronics Pty. Ltd.) and Magellan Meridian GPS

Plate 4.3.b. (Foreground) Weather station (WM-918 Electronic Weather Station) and data logger (Data-Pak) & (background) battery pack (4 x 8v. rechargeable batteries)

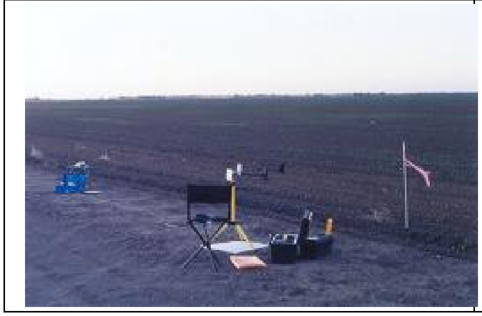


Plate 4.3.c. Microbat sampling equipment
(IC) irrigated cropping Site Ha in spring, "Cardale"

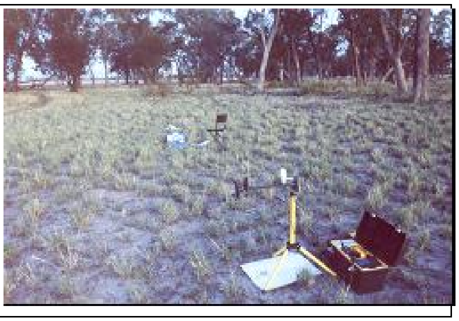


Plate 4.3.d. Foreground - Portable weather vein and compass (for sensing temperature, humidity, wind direction and speed), weather station & data logger in box, battery pack behind, and background Anabat II recorder and stool (GB) grey box site Hi "Cardarga"

Harp trap survey Spring 2003

Plate 4.3.e. (CP) near Site GJ in spring
Microbat harp trap within a cypress pine remnant, "Cardarga"

Plate 4.3.f. (RGF) river red gum forest site (Ca) late spring "Mollee" : 10 *Chalinolobus morio* captured including 3 lactating females (in the trap to right of vehicle) & highest microbat call abundance (134 calls within 20min sample) (Note: groundcover containing lippia)

Ethics approval

To conduct research using an Anabat bat recorder harp traps and cyalume light tags, research ethics approval was acquired from the University of Sydney Animal Ethics Committee, and a Research license was obtained from the New South Wales Department of Environment and Conservation.

4.4. RESEARCH DESIGN

Echolocation

For most microbat research using Anabat recorders, the recorders are either left overnight at individual locations, or recording is conducted whilst walking along transects (Ellison *et al.* 2005). When comparative sampling has been required a number of recorders have been employed to sample the same night at different locations (Erickson and West 2003, Lumsden 2004, Lumsden and Bennett 2005, Cavanagh *et al.* 2005). Very little comparative research has been undertaken using one recorder to record at different locations at different times during the night (Kusch *et al.* 2004). For the current research project it was essential that the ten landscape categories be sampled as close as possible to the same: discrete seasonal stages during the 180 day cotton production cycle; stages of climatically and crop-induced associated insect populations and pressure; and moon cycles. Black clay soil types in areas of cotton production limit vehicle access and movement to main roads after even very low rainfall events. . These constraints and the use of one Anabat recorder required a compact sampling survey design to facilitate the best opportunities for both spatial and temporal comparisons. Thus recording microbat calls for 20 minutes was determined as the length of sample to be undertaken at identified sample sites.

Sample sites - step wise random stratification design

The 1998 and 2003 aerial photographs of the study area (LPI 1998 and 2003) and property plans obtained from the landholders, Phil Norrie, Mike Carberry and Alan Goode, were combined to produce a map defining the vegetation and management landscape elements as well as fencelines, water storages and associated water channels. The location of sampling sites was achieved with the use of a 2,000 m² numbered grid overlay, the combination map and random sampling tables. Numbers of sites for each category were curtailed when an approximation of the landscape representation for that category was achieved.

Sampling protocols

Spring, summer and autumn were determined as appropriate sampling survey times. For each night of sampling a schedule of sites was established to include a range of vegetation and management categories and an order of sampling. Allowances were made for the following constraints: no interference with farming operations; rapid movement across the three properties; use of existing farm roads and tracks; negotiation around fences, gates, water channels, fields and paddock; and the necessity for quick access to fields and remnants. Random seasonal variation in sample order was built into the design wherever achievable. To capture as much microbat call activity as possible, between each 20-minute sample a 15-minute maximum was allocated for disassembly, movement and equipment reassembly at the next site.

Plate 4.4. Equipment transportation between sample sites

The three main variables affecting the transmission of sound through the atmosphere are air pressure, temperature and relative humidity (Corben 2003). For the assessment of climatic influences upon both microbat activity and the efficacy of the Anabat recorder (Corben 2003) climatic data was collected at two minute intervals during each 20 minute recording sample using a portable weather station (WM-918 Electronic Weather Station and WeatherView 2001 software) and data-logger (Data-Pak and software) (Plate 4.3b, c & d). The climatic data collected included maxima and minima temperature, humidity, wind speed and due point. Power was provided to all equipment, with exception of the GPS unit, by a battery pack containing four eight-volt interconnected rechargeable batteries. All equipment was housed in strong plastic tool boxes with handles for easy and speedy movement between sample sites (Plates 4.3a & b and 4.4). Other field equipment included timer, compass, head lights, sampling schedules, note pad and stools (Plate 4.3c and d, 4.4).

Each sampling night the weather station was set using barometric pressure at sea level which, together with times for ‘sunset’, ‘civil twilight’, ‘moonrise’, ‘moonset’ and ‘moon phase’, were sourced from The Bureau of Meteorology website (http://www.bom.gov.au/weather/nsw/observations).

To enable quick site location at night each site was marked just prior to that evening’s sampling with a pole, fluorescence tape and marker ribbon (Plate 4.3c).

Standardisation and reduction of interference between parameters

No sampling was conducted when winds exceeded 10 kpa, or during rain events. Due to restrictions in movement on the black soils across much of the research area, sampling was delayed for several nights after rain events. After the Exploratory Survey (EA03), full-moon conditions were avoided whenever possible to counter possible impacts upon both insect and microbat activity (Kanuch and Kristin 2005). The phase and status of the moon and cloud cover were noted for each site, as well as the Geographic Positioning System (GPS) location (Magellan Meridian GPS) (Plate 4.3a).

To avoid any possible interference with the Anabat recorder, the weather station was located 12 to 15m behind the Anabat recorder. Both were connected to the battery pack. The Anabat recorder was turned "On" at low volume during sampling sessions enabling the researcher, sitting between the weather station and recorder, to observe incoming call variations and interference. Field notes were made after recording had commenced at the subsequent site. Although production practices such as plowing, planting, irrigating, spraying and picking resulted in extensive nocturnal noise and activity across much of the study area, during sampling surveys noise and movement by the researcher were kept to a minimum.

To avoid call distortion by clutter (Corben 2003) the Anabat recorder was directed at spaces, or spaces between trees, rather than directly at trees. The exceptions were grasslands sites where the recorder was directed towards distant isolated trees if present. Where sample sites fell at the junction of two differing landscape categories ie. IC/DC (irrigated cropping/dryland cropping), or IC/RGOW (irrigated cropping/river gum open woodland), the Anabat recorder was directed (Corben 2003) at the landscape category allocated for that site. Adjacent landscape categories were noted but not included in the analysis.

The Anabat II bat recorder Sensitivity and Division Ratio were set at 7.5 and 16 respectively. To facilitate sampling equality, in all landscape categories the Anabat recorder was placed on a small folding camp stool directed upward at a 45º angle. However at a few sites during spring and summer, insect call activity (Corben personal communication 2004) was so extensive and disruptive the recorder was directed upward at a 90º angle, thus changing the cone of reception (Corben 2003).

At the completion of each night of sampling, climatic data was downloaded onto a computer and the battery pack recharged. Calls were downloaded at the completion of the survey.

4.5 SURVEYS OF MICROBATS ACROSS THE LANDSCAPE

To commence the field sampling process, in autumn 2003 an exploratory survey (EA03) was conducted recording microbat ultrasound echolocation activity to assess (i) microbat presence in cotton production landscapes, (ii) microbat activity over cotton fields in autumn, and (iii) the design for the field research. From the results of this survey a set of comparative spring, summer and autumn seasonal surveys (SSA03/04) was designed for implementation over the 2003/04 cotton season.

SURVEY 1 - The Exploratory Survey – Autumn 2003 (AE03 survey)

To fulfill the requirements of the AE03 survey the proportional representation of cropping sites was altered (Fig. 4.5a.) by the following factors:

(i) reduced microbat habitat in cropping areas in late April (autumn) as these categories consisted of either fallow fields, ploughed fields and, fields of defoliated or picked cotton plants. (Plate 4.1b)

(ii) the limitation of available sampling nights before presumed hibernation due to rapidly reducing nocturnal temperatures.

Therefore a total of 102 sites, with a strong concentration on native vegetation categories, was identified.

Adjustments to research methodology during Exploratory Survey 1 (EA03), with implications for future surveys

Initial planning allowed 20 minutes sampling at 18 sites per night between dusk and dawn. By the end of night 2 it was apparent that with little call activity after 3 a.m., the results for any sites sampled after that time would seriously skew the overall results. After verification on the third night sampling times after 2 a.m. were abandoned for the remaining nights sampled.

Although a 15-minute relocation period was scheduled, relocation varied from 10 to 29 minutes, and in one instance expanded to 61 minutes and the abandonment of four sites. These variations, indicating either the distance traveled or the difficulty of movement across the landscape, had implications for temporal as well as spatial comparisons of activity. Shorter and more clearly defined routes were required.

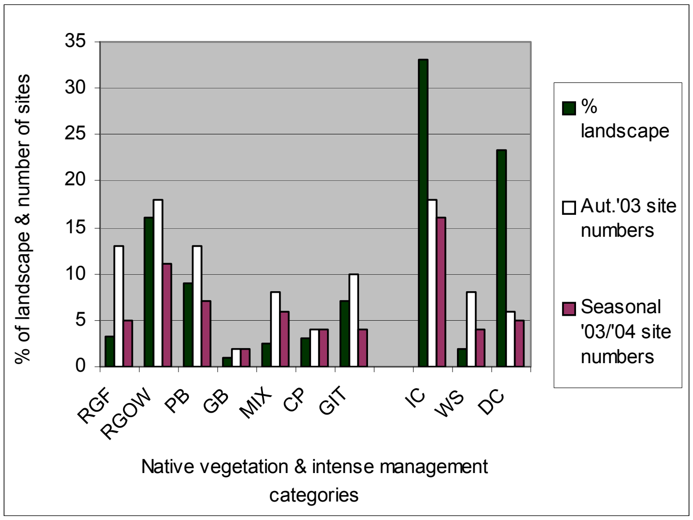
Light intermittent drizzle during sampling day 7 and night resulted in the reduction of, (i) access to sampling sites other than sandy ridges or sealed roads, (ii) the number of sites sampled, and (iii) the recording clarity. As time constraints were becoming a major concern sampling was continued with the Anabat recorder protected by cover from the back of a 4x4 drive vehicle. Calls, although reduced in number and clarity, were nevertheless recorded throughout all sampling times. Rain over the following week precluded repetition.

SURVEY 2 - Seasonal Landscape Surveys 2003/04 (SSA03/04 surveys)

The three major alterations made to the autumn survey (EA03) methodology for the SSA03/04 seasonal surveys were to the (i) numbers of sites sampled for each landscape category, (ii) time of the night sampling was conducted, and (iii) route length for each sample night.

Sample sites

To facilitate clearer spatial and temporal comparisons of microbat landscape utilisation, a second stage of the random stratification sampling design was adopted. Sampling surveys were consolidated by both restricting and increasing the sample site inclusion to three sites per 2,000 m^2 grid section (ie 3 sites in 4,000,000 m) across the whole study area. In this manner a more proportional representation of landscape categories was achieved. For each landscape category, a comparison between the proportional percentage of the study area, and the number of sites sampled during (i) the Autumn 03 Exploratory Survey(EA03), and (ii) the spring, summer and autumn SSA03/04 seasonal surveys, is shown in Fig. 4.5a. Sites were adjusted wherever appropriate to exclude high proportions of large fallow field sites in the irrigated and dryland cropping categories .



KEY

Native vegetation categories:

RGF	river red gum forest/woodland adjacent to river
RGOW	river red gum open woodland/scattered trees on extended flood plain
PB	poplar box
GB	Pilligar grey box
MIX	mixed remnant poplar box, grey box & belah
CP	cypress pine
GIT	grassland / isolated trees

Intense management categories:

IC	irrigated cropping
WS	water storage
DC	dryland cropping

Fig. 4.5.a. Landscape category comparisons –
(i) % of total landscape represented by landscape category;
(ii) numbers of sites sampled in the autumn 2003 exploratory survey (EA03) reflecting autumn cropping status and a concentration on sampling vegetation categories not cropping areas; and
(iii) numbers of sites sampled in the SSA(03/04) spring 2003, summer & autumn 2004 surveys, reflecting more equitable proportional landscape category representation.

One hundred and two sites were sampled across seven nights in autumn 2003 (AE03), compared to 64 sites sampled over eight nights in each SSA03/04 seasonal survey (Table 4.5a). The individual sites sampled during the SSA03/04 surveys are marked by their individual landscape category in Fig 4.5b. The land in the southeast corner of Fig. 4.5b was excluded from sampling due to difficulty of access and disparity of vegetation and landscape type from the remainder of the study area. Photographs of a representative set of landscape categories and sampled sites are included in Attachment 4 (Plates 4Ai to 4Axii).

Table 4.5.a. Landscape scale microbat surveys conducted in the project area 2003/04

Anabat Landscape Survey Time	Number of nights sampled	Number of sites sampled
Autumn (20-26 April 2003)	7	102
Spring (10-30 November 2003) **	8	64
Summer (28 Feb-8 March 2004	8	64
Autumn (8 – 16 May 2004)	8	64
TOTAL SITE VISITS	31	294 *

KEY: * many autumn 2003 survey sample sites were retained for the seasonal surveys; ** included trapping

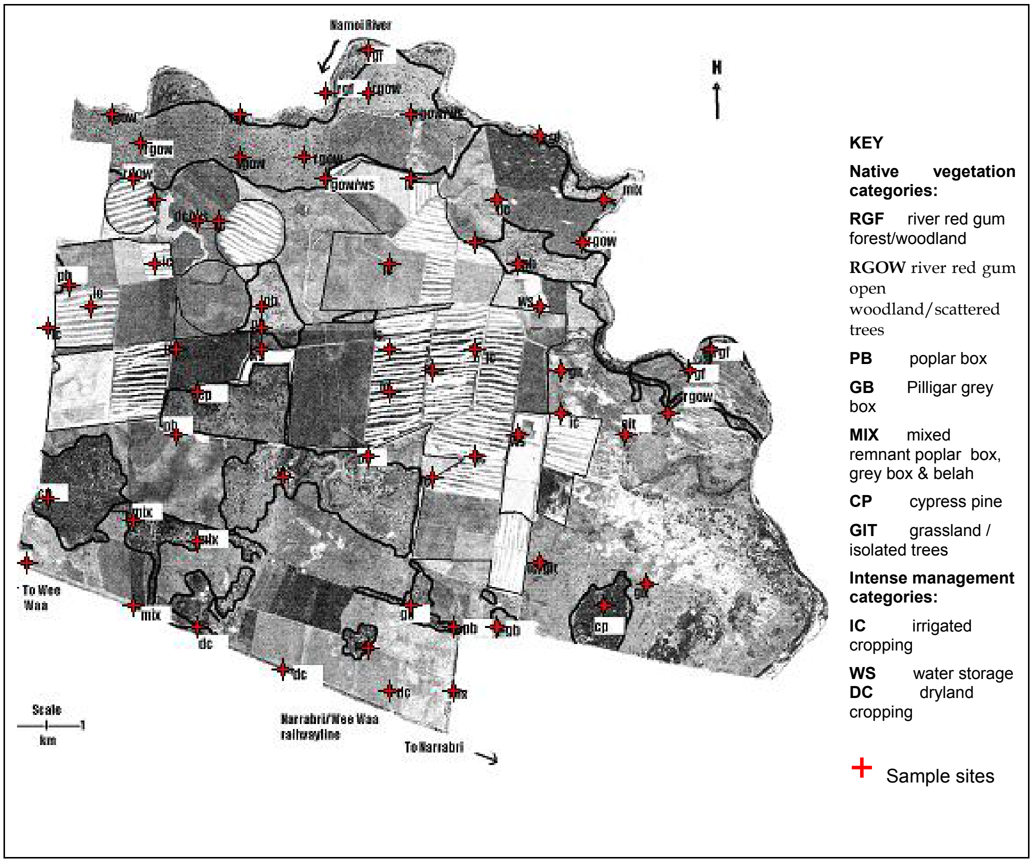


Fig. 4.5.b. Research area, sample sites (red star) and their landscape categories for the Seasonal Surveys 2003/04 cotton season (2003 aerial photograph - Land and Property Information, Bathurst)

Sampling time

Seasonal

Rain events combined with a period of low diurnal and nocturnal temperatures after planting caused protraction of the 2003/04 cotton season resulting in slow early crop development and consequent late defoliation and picking (late April/early May). The timing of the SSA03/04 seasonal surveys was determined by the cotton crop development. The spring survey, incorporating most of the harp trap survey, was conducted between 16th-30th November 2003 (5 to 7 leaf stage), the summer survey between 28th February and 9th March 2004 (full flower stage), and the autumn survey between 8th-16th May 2004 (immediately post defoliation and picking). Circumstances outside the control of the researcher prevented summer sampling during January and early February, the optimum time for insect pest pressure in cotton fields. Thus the possible associated higher levels of microbat activity would not have been recorded

Nocturnal

Since there was an absence of microbat activity immediately after sunset during the AE03 survey, the sampling commencement time was re-assessed. Completion time for microbat sampling was set at approximately 12.30am.

As microbat calls recorded with an Anabat recorder are time and date stamped and recording equipment can be set to commence automatically, many studies utilise "sunset" as the sampling commencement time. To facilitate recording any microbat activity within the first 20-minute sampling session the commencement time for the current study was critical. "Sunset", "civil twilight" and "nautical twilight" were investigated as alternatives for the commencement time and are set out below (Geoscience Australia website).

Sunset	defined as the instant in the evening under ideal meteorological conditions, with standard refraction of the sun's rays, when the upper edge of the sun's disk is coincident with an ideal horizon;
Civil twilight	defined as the instant in the evening, when the centre of the sun is at a depression angle of degrees (6°) below an ideal horizon. At this time in the absence of moonlight, artificial lighting or adverse atmospheric conditions, the illumination is such that large objects may be seen but no detail is discernible. The brightest stars and planets can be seen and for navigation purposes at sea, the sea horizon is clearly defined;
Nautical twilight	defined as the instant in the evening, when the centre of the sun is at a depression angle of twelve degrees (12°) below an ideal horizon. At this time it is dark for normal practical purposes.

Because of the extent of ambient light during spring and summer in the study region and the tested lack of microbat call activity between sunset and civil twilight, "civil twilight" was ascertained as the appropriate commencement time for the spring and summer SSA03/04 surveys. At the dates of the surveys "civil twilight" was approximately 36 and 24 minutes after sunset in spring and summer respectively. With a lack of ambient light in autumn, "sunset" was utilised as the commencement time for the SSA03/04 autumn survey (Table 4.5b). On the sampling dates in autumn civil twilight was approximately 15 minutes after sunset. Local sunset and civil twilight data was accessed from Australian Government/Geoscience Australia (website). The nocturnal sampling time structure is set out in Table 4.5b. The 20-minute sampling time-of-night sessions will be referred to throughout this study as "Time 1 to Time 8" (T1-T8).

Table 4.5.b. Nocturnal sampling "Time of night" structure for the three SSA03/04 surveys

	Sample times **approx. minutes after civil twilight (spring & summer) & sunset (autumn)**							
	Time 1	**Time 2**	**Time 3**	**Time 4**	**Time 5**	**Time 6**	**Time 7**	**Time 8**
Minutes after civil twilight/ sunset	ct/s-20 m. after ct/s	35-55 m. after ct/s	70-90m. after ct/s	105-125 m. after ct/s	140-160m. after ct/s	175-195m. after ct/s	210-230m. after ct/s	245-265m. after ct/s

KEY (ct) civil twilight; (s) sunset; (m) minutes.
Spring– 16-30 November, '03 (5-7 leaf) – **civil twilight** 1956–2014 d.s.t. (sunset approx. 36 min. before ct)
Summer– 28 Feb.-9 March, '04 (full flower) – **civil twilight** 2001–1950 d.s.t. (sunset approx. 24 min. before ct)
Autumn – 8-16 May '04 – (defoliated & picked) - **sunset** 1820-1814 e.s.t. (sunset approx. 15 min. before ct)

Final design for the SSA03/04 seasonal surveys

Accordingly the SSA03/04 survey research design consisted of eight nightly sets of eight twenty-minute sampling time slots, replicated in spring, summer and autumn. Each twenty-minute sampling time slot was separated by a fifteen-minute relocation time. The order in which sites were sampled was randomly varied seasonally, within movement constraints. The details of the sampling design are set out in Table 4.5c.

Table 4.5.c. The sampling design for three SSA03/04 Seasonal surveys showing 8 nightly sets of 8 sample sites and their landscape categories, and the "Time of night" sampling order for each season.

Night ID (order of sampling Sp. Su. Au.)	Site ID	NatVeg/ IntMan category	Time slot (Spr. Sum. Aut.)	Night ID (order of sampling Sp. Su. Au.)	Site ID	NatVeg/ IntMan category	Time slot (Spr. Sum. Aut.)	Night ID (order of sampling Sp. Su. Au.)	Site ID	NatVeg/ IntMan category	Time slot (Spr. Sum. Aut.)	Night ID (order of sampling Sp. Su. Au.)	Site ID	category	Time slot (Spr. Sum. Aut.)
(1)(4)(7)	Af	RGOW	1,4,8	(3)(2)(5)	Bs	DC	1,6,8	(5)(1)(3)	Ca	RGF	1,5,7	(7)(8)(4)	Hi	GB	1,8,7
	Ai	RGOW	2,5,7		Ak	IC	2,7,7		Cd	MIX	2,6,6		Hj	MIX	2,7,8
	Ad	RGOW	3,6,4		Bk	IC	3,8,6		Ce	RGOW	3,7,8		Gn	DC	3,6,6
	Ac	RGOW	4,8,5		Bi	RGOW	4,1,5		Ci	PB	4,8,5		Hk	MIX	4,4,5
	Ab	RGOW	5,7,6		Bm	RGOW	5,5,1		Hd	IC	5,4,2		Gk	CP	5,1,4
	Ao	IC	6,3,1		Bb	RGF	6,2,4		Hf	IC	6,3,1		Gj	CP	6,2,3
	Ar	WS	7,2,3		Bd	RGOW	7,3,3		Hg	PB	7,2,3		Gh	MIX	7,3,2
	Cj	GIT	8,1,2		Bc	RGF	8,4,2		Hh	IC	8,1,4		Gg	MIX	8,5,1
(2)(6)(2)	Ha	IC	1,4,5	(4)(5)(1)	Fm	GIT	1.8.8	(6)(3)(8)	Ej	PB	1,8,4	(8)(7)(6)	Aq	IC	1,4,2
	Hb	IC	2,5,4		Fn	CP	2,7,7		Ei	PB	2,7,5		Eh	IC	2,3,7
	Dn	GIT	3,6,7		Hc	IC	3,6,5		Em	IC	3,3,8		Di	CP	3,6,4
	Cnn	PB	4,7,3		Dk	WS	4,1,6		Ee	IC	4,2,6		Hl	WS	4,8,1
	Co	MIX	5,2,8		Cl	GIT	5,2,4		Ef	DC	5,1,7		Dg	PB	5,7,5
	Da	GB	6,3,6		Fb	RGF	6,4,1		Ec	IC	6,6,2		Dj	WS	6,5,3
	Cr	DC	7,8,1		Fc	RGF	7,3,2		Eb	RGOW	7,5,1		En	IC	7,2,6
	Go	DC	8,1,2		Ff	RGOW	8,5,3		Ea	PB	8,4,3		Eo	IC	8,1,8

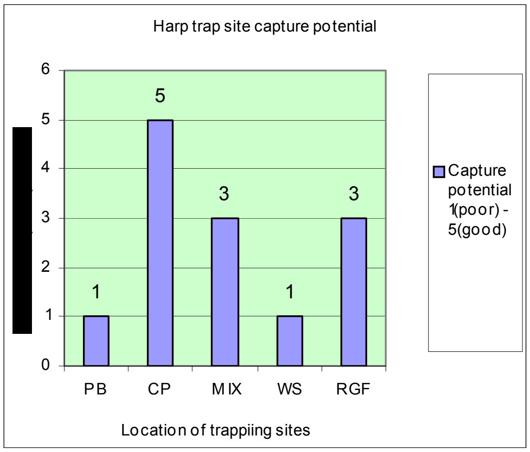
SURVEY 3 - Capture of microbats with harp traps, spring 2003

The spring SSA03/04 seasonal survey was accompanied by capture of microbats using harp traps to verify species identified using Anabat technologies. The numbers of sites and nights sampled are shown in Table 4.5d.

Table 4.5.d. Harp trapping of microbats during Spring 2003

Number of surveys conducted	Number of sites sampled	Number of nights sampled
1	5	10

The location of suitable trapping sites was problematic due to the open characteristics of the cotton production landscape. The sites sampled represented five of the ten different landscape categories. In order of sampling these were: (i) isolated small stand of poplar box within a scattered poplar box community (PB); (ii) within a dense predominantly cypress pine forest (CP); (iii) at the edge of a small water storage (WS); (iv) within a mixed (poplar box, grey box, belah) open woodland roadside remnant (MIX); and, (v) a clearing within a red river gum forest/woodland adjacent to the river (RGF). Extensive microbat ultrasound activity had previously been recorded at all five locations. Only within the CP (cypress pine) remnants that contained narrow tracks enclosed by thick forest growth, were there good sites for harp trap location. Based on the openness of the landscape a rating, (1 lowest and 5 highest) for the likelihood of bat capture was given for each of the trapping locations (Fig. 4.5c).



KEY

Native vegetation categories:

(RGF) river red gum forest adjacent to river;
(PB) poplar box isolated small group;
(MIX) mixed remnant poplar box, grey box & belah;
(CP) cypress pine;

Intense management categories:

(WS) water storage

Fig. 4.5.c. Microbat capture potential of the 5 harp trap locations

Five harp traps were established across any obvious or suggestive flight paths, at locations in the vicinity of the identified sites. The traps remained at each site for two nights. The traps were checked around midnight for capture of any lactating females, and at 6 a.m. Captured microbats were placed in individual cloth bags and transported to an air-conditioned quiet house in Narrabri for examination, measurement and identification using the Key in Churchill (1998). The bats were returned and released at the capture site immediately after dusk the subsequent evening.

For each microbat captured, forearm length, weight, age, sex, sexual maturity and species were recorded, and each microbat photographed. A hair sample and faeces were collected for possible later use. Measurements were made using a Bergeon 0.1mm rule, and weights were ascertained using a cloth bag and a set of Pesola precision scales max. 30g. Other assessments were arrived at using Churchill (1998) as a guide Penis examination was kept to a minimum as experience in handling microbats was very limited. The identification of captured bats, was verified by Michael Pennay (pers. communication), after examination of the biological data, the photographic records and the release calls.

At the time of release the night after capture, a fluorescent cyalume light tag (mini sized fishing lights – weight 0.1 g), was activated and lightly attached to the underbody fur of each bat using a thin single layer of Skin Bond surgical cement (Smith and Nephew), and the bat released from the hand immediately. Capsules remain attached for only short periods of time (approx 30 minutes to several hours) before falling off or being groomed off, with no depletion of fur in the process (Lumsden person. communication 2003). The direction of the illuminated flight path was then followed with an Anabat recorder, facilitating an accurate and in most cases extended, record of each release call. Time of release for each identified bat was noted to enable matching calls. Due to the regional variation in the calls of some species (Reinhold *et al*. 2001, Law *et al.* 2002) and the limited availability of regional calls, this small data set will be added to regional knowledge in a forthcoming Law and Pennay publication.

Violent wind and hail storms interrupted trapping and prompted trap repair (www.faunatech.com.au). The consequent disruptions, the limitations in time and resources, and the interruptions to the Spring SSA03/04 landscape survey, restricted the extent of this survey.

4.6 THE DATA SET AND ANALYSIS

Ultrasound Data set

Recorded ultrasound calls were downloaded into a laptop computer with Windows 1998 operational system. The computer software used for recording calls was Anabat 6 and for the viewing of calls as frequency vs time graphs, Analook software was used (Titley Electronics Pty. Ltd., Corben 2000a and b).

Altogether a total of 13,600 ultrasound files were recorded between April 2003 and May 2004 which included all microbat calls (1>1pulse), insect stridation and ultrasound calls, and interference. Files included 1,050 from 102 sites in the EA03 April 2003 survey, and 12,550 from 192 site visits during the SSA03/04 surveys between November 2003 and May 2004 (Table 4.6).

Rather than subjecting this data set to complex multi variate statistical analysis, an approach was undertaken to stratify and standardise data sets, eliminating as many non-functional variables as possible.

Table 4.6. Landscape scale microbat ultrasound echolocation activity surveys conducted in the project area 2003/2004.

Anabat Landscape Survey Time	Number of nights sampled	Number of sites sampled	Total number of calls recorded *
AE03 - Autumn (20-26 April 2003; post defoliation and picking)	7	102	1,050
SSA03/04 - Spring (10-30 November 2003; 5-7 leaf stage) ***	8	64 #	3,843
SSA03/04 - Summer (28 Feb - 8 March 2004; full flower prior cut-out)	8	64 #	5,450
SSA03/04 - Autumn (8 –16 May 2004; immed. post defoliation & picking)	8	64 #	3,257
TOTAL	31	294 site visits **	13, 600

* includes all microbat calls (1pulse and above), insect stridation and ultrasound calls, and interference
** many of the AE03 sample sites were retained for the SSA03/04 seasonal surveys
\# sampled the same 64 sites.
*** included trapping

“Total call abundance” was used as an overall discrete measure to examine the utilisation of the landscape by the entire bat community. This represents a different focus for a study that attempts to sample the landscape utilisation by the bat community. Such an approach was also found suitable for the comparison of seasonal and temporal variation.

Bat activity was investigated by identifying various call characteristics indicating flight activity, searching for prey, or feeding. These three categories were identified from the literature and used to separate calls in order to characterise two main activities: navigating and prey searching activity and feeding activity.

Microbat activity was characterised in three different ways,

- bat community activity,
- bat guild activity and
- individual bat species activity.

Activity patterns of microbats and insects were examined according to season and time of night. A separation of total call abundance during these time intervals into maximum, minimum, median, mean, and upper and lower quartile statistical parameters was used to identify differing sets of influences. No attempt was made to compare call abundances between species and sites, as it was deemed that at this stage of understanding in bat ecology and for the purpose of this research it was more appropriate to look at overall patterns related to cotton production systems and landscapes.

Call analysis

Definitions of microbat ultrasound echolocation calls as described in Reinhold *et al.* (2001) and Pennay *et al.* (2004) have been used in this thesis. Calls are made up of a series of sound pulses repeated at regular intervals. A consecutive string of pulses made by the same bat is referred to as a "sequence". A "pass" is defined as a continuous sequence of calls by a single bat, from the time it is first detected until it has traveled beyond the range of detection. The term "call" in the context of this study is synonymous with "pass".

Calls composed of fewer than three sound pulses, although not used for the identification of species, were included as calls in call abundance related to sample time, sample site, or landscape category.

Because of the interrelationships between microbats and insects in this study, insect calls were also analysed (SSA03/04 surveys only). Although the main cotton insect pests do not use ultrasound, an increasing number of insects species, many of which frequent cotton fields, have been found to utilise ultrasonic sounds for specific activities (Spangler 1988, Fullard *et al*. 1994, Greenfield and Weber 2000, Faure and Hoy 2000, Surlykke 2001, Greenfield and Baker 2003, Jones and Rydell 2003, Miller Narins *et al*. 2004). Such useage of ultrasonic sounds may influence or interfere with microbat activities over cotton fields eg. tiger moths, which utter an ultrasonic reply to indicate unpalatibility (Hristov and Conner 2005.) Insec`t data has not been included in the body of the thesis but included in accompanying CD because of its relevance to the cotton industry.

Both microbat and insect calls were later divided into five call length categories – very short (1-5 pulses), short (6-10 pulses), medium (11-20 pulses), long (21-40 pulses) and very long (>40 pulses). Insect calls (a series of regular pulses) were segregated from overall "noise" (without any regular pulse pattern) (Corben 2004 pers. comm.).

The analysis and identification of microbat and insect calls was undertaken using a combination of Analook quantitative measurements (Caddle & Lumsden 1997), and other qualitative structural features (de Oliviera 1998, Reinhold *et al.* 2001, Pennay *et al.* 2004). Although the characteristic frequency (Fc) and the pulse shape were the initial defining call characteristics for microbat call identification, the parameters utilised in this study were:

Analook quantitative measurements: (Caddle & Lumsden 1997):

Fmax	maximum frequency;
Fmin	minimum frequency;
Fc	characteristic frequency (referring to the flattest part of the pulse);
N	number of pulses currently displayed on screen;
Dur	duration of pulse msecs;
Tc	time into the pulse when the characteristic frequency is reached; and

Qualitative structural features :

- Frequency type - CF (constant frequency); FM (frequency modulated) and/or alternating and/or descending, or a combination of both (de Oliveira 1998, Reinhold *et al*. 2001);
- Pulse shape (de Oliveira 1998);
- Call phase – search, attack, feeding buzz (when calls were long enough to differentiate) (Pennay *et al.* 2004).

Calls recorded at release during the Spring 2003 Harp Trap Survey were assessed by Michael Pennay for correct species identification (Pennay personal communication 2004) and were used for appropriate species call identification during all three SSA03/04 seasonal surveys.

For each call, the date, time, location, and call parameters were entered onto Excel spreadsheets.

4.7 STUDYING THE MICROBAT COMMUNITY

The subjects examined in this thesis fall into three sections: microbat diversity, and temporal and spatial distribution. Temporal distribution includes the nocturnal and seasonal examination of call and feeding buzz activity patterns. Relational patterns of microbat call and buzz and insect activity, and the influences of climatic and moon variables upon the patterns of activity were examined but due to the inconclusive results and Thesis length criteria were included only as Addenda to this thesis. Spatial distribution commences with the establishment of a suitable guild structure to facilitate comparisons of seasonal landscape distribution for guilds and individual species. For these sections differing methodological requirements needed to be met which are outlined below.

Diversity

Data from all four surveys (AE03, SSA03/04 and the Capture Survey) is utilised for this chapter.

Identification of the AE03 survey calls was conducted using the only available key at that time, “Key to the bat calls of south-east Queensland and north-east New South Wales” (Reinhold *et al.* 2001). Other references included Herr (1995), Caddle & Lumsden (1997), de Oliveira (1998), Corben & O’Farrell (1999), and Richards (2000 pers. comm.). Lack of resources for trapping as well as the late autumn time frame did not allow trapping and the collection of local reference calls.

Identification of the SSA03/04 survey microbat calls was undertaken using “Bat calls of New South Wales” (Pennay *et al.* 2004), together with the knowledge and experience gained from analysing the AE03 data set, Law *et al.* (2002), Corben (2004 personal communication) and Pennay (2005 personal communication). The very clear and extensive calls that were recorded of species released during the Spring 2003 capture survey and authenticated by Pennay (personal communication 2004) were used together with the regional reference calls in Pennay *et al.* (2004) .

The identification of the captured bats utilised the “Key to identifying bat families” and the biological measurements described in Churchill (1998). The examination of the release calls, either confirmed (the majority) or revised the identification of captured bats (Pennay *et al*. 2004). The identification of captured bats, was verified by Michael Pennay (pers. communication), after examination of the biological data, the photographic records and the release calls.

Temporal distribution

Chapters in this section utilised nocturnal sampling time structure. For spring and summer, the seasonal comparisons were made by the combination of data from eight sampling times replicated by eight nights, that is, each sample time (T1-T8) is representative of data collected over 160 sample minutes. In summer, recording on Night 5 was abandoned after sample T4 due to sudden rain. When sampling was resumed crop spraying and irrigation constraints restricted sampling at the remaining sites to Times 1-T4. Accordingly data for the fifth night of summer sampling included a duplication of sampling for T1-T4. The second set of summer night 5 data for T1-T4 has been omitted for these chapters. Thus for summer, T1-T4 results include sampling on eight nights (160 sample minutes for each time), and T5-T8 results include sampling on seven nights (140 sample minutes for each time).

Two call characteristics were utilised to examine feeding patterns. These were “length of call” and “feeding buzz”. The length of call was determined by the number of pulses for each call utilising Analook (Titley Electronics Pty Ltd., Corben & O’Farrell 1999) measurements of “F7”, “Z” to clear all clutter from the calls, and the number of pulses “n”. In overlapping calls made by more than one species the number of pulses was counted manually. Although some feeding buzzes may not have resulted in actual prey capture (Jones and Rydell 2003), call phases displaying feeding buzz characteristics (Pennay *et al.* 2004) were counted as a buzz. It was necessary only to assess activity and not success. Where there was an uncertainty in the identification of feeding buzzes contained in long or overlapping calls, buzzes were excluded. Buzzes contained within calls not identified to species level (with the exception of *Nyctophilus* spp.) were also excluded.

Although the intention in the use of an Anabat recorder was to record microbat ultrasound activity, the activity of other ultrasound emitting organisms was captured consequentially. Because of the interconnectedness of microbat and insect usage of ultrasound, other collected calls were analysed. The two call characteristics utilised were “call” and” “length of call”. The number of pulses made by more than one organism in overlapping calls, were counted manually. Calls without a definite pulse pattern (Corben 2004 personal communication) or composed of general noise, were excluded.

A separation of total call abundance during nocturnal time intervals into maximum, minimum, median, mean, and upper and lower quartile statistical parameters was used to identify differing nocturnal and seasonal patterns of activity. The seasonal and in some cases nocturnal patterns of correlationsbetweenvariables were determined using Principal Component Analysis technologies (Genstat 8.1. 2005).

Activity Graphs and Indices

Seasonal activity patterns for individual species were examined and a set of comparative seasonal graphs was prepared in Chapter 6.2**.** Due to temporal variations in microbat activity across the study area, seasonal, or nocturnal and seasonal Indices were constructed for species richness, assemblage activity and assemblage feeding (Table 4.7).

Table 4.7. Microbat Indices

Indices	Temporal range	Chapter
Microbat Species Richness Index	seasonal	6.1.
Microbat Assemblage Activity Index	nocturnal & seasonal	6.2.
Microbat Assemblage Feeding Buzz Index	nocturnal and seasonal	6.3.

The influence of climate and moon variables (included only as Addenda on the accompanying CD)

The climatic data included ten sets of climatic data for each 20-minute survey sample. For each 20-minute sample minimum and maximum scores were extracted for temperature, humidity and wind speed. Moon scores ranged from a score of “0 not present" during the 20-minute sample, to a score of "5 for full moon presence the whole 20 minutes". "Moon presence" also included allowance for cloud cover. Although the full-moon phase of the moon cycle was avoided wherever possible, the stage of crop development and other external restraints determined the survey date and therefore the phase of the moon cycle.

The seasonal and nocturnal influences of climate moon and other variables on microbat and insect call and feeding buzz abundance were documented by summary variables for temperature, humidity, wind, rain and moon cycles. Seasonal and nocturnal patterns of correlations, in order of strength of the individual variables, were determined by principal component analysis. All analyses were conducted using Genstat 8.1 (2005).

Spatial Distribution

A suitable guild structure

The species identified in the study area were examined against past guild classifications. They were then grouped into guilds according to the ultrasound echolocation frequency used by individual species (4.7 Diversity above), and the known ranges of ultrasound frequencies to which insects are most sensitive. An array of parameters from literature including forearm length, body weight, ultrasound frequency and call type, foraging area and prey preference, was assessed against the selected guild group structure. The guild structure was used in the subsequent chapter to examine landscape patterns of distribution and utilisation for the assemblage of microbats across the study area. A set of graphs was developed for each guild incorporating the known landscape foraging patterns for individual species identified in the study.

Microbats and vegetation

The numbers of sites (in brackets) and the abbreviations for each landscape category used in this chapter were:

Native vegetation categories	**Number of sites**	**Intensive agricultural management categories**	**Number of sites**
(A or rgf) river gum forest	5	(H or ic) irrigated cropping	16
(B or rgow) river gum open woodland	11	(I or ws) water storage	4
(C or pb) poplar box	7	(J or dc) dryland cropping	5
(D or gb) grey box	2		
(E or mix) mixed species	6		
(F or cp) cypress pine	4		
(G or git) grasslands and isolated trees	4		

With some variations the landscape categories in this section are arranged in approximation of their location to the Namoi River. Whilst for the native vegetation category (A) river red gum, is adjacent to the river, and (F) cypress pine, and (G) grasslands and isolated trees, are the furthest from the river, for the intensive management categories (H) irrigated cropping, is situated between (B) river red gum open woodland, and either (C) poplar box, (D) grey box, or (E) mixed species remnants. Water storages (I) are located adjacent to (H) irrigated cropping, and (J) dryland cropping is located both closer to the river between (B) river red gum open woodland, and (C) poplar box, as well as, the most distant category from the river.

Throughout this section and the Attachments, the following abbreviations were used for the microbat species identified in the study area. The taxa are arranged here in guilds of ascending ultrasound frequencies.

Guild 1	(T.a.) *Tadarida australis*; (S.f.) *Saccolaimus flaviventris*
Guild 2	(M.4) *Mormopterus* sp. 4; (C.g.) *Chalinolobus gouldii*; (unid) unidentified group of calls; (M.2) *Mormopterus* sp. 2; (M.3) *Mormopterus* sp. 3; (S.b.) *Scotorepens balstoni*
Guild 3	(S.g.) *Scotorepens greyii*; (C.p) *Chalinolobus picatus*; (V.r.) *Vespadelus regulus*; (V.d.) *Vespadelus darlingtoni*; (V.v.) *Vespadelus vulturnus*
Guild 4	(C.m.) *Chalinolobus morio*; (V.t.) *Vespadelus troughtoni*; (N. spp.) *Nyctophilus* spp.

The distribution of bats across the landscape was specified for different seasons and different categories of vegetation and was examined in two parts using: (A) call abundance, and (B) taxa and guilds or functional groups. Both sections examined distribution separately across (i) native vegetation and (ii) intensive management land cover variables and finally across (iii) the combined cultural landscape. Call abundance distribution included seasonal comparisons of % feeding efficiency, absence/presence, and the influence of individual sites including cotton varieties using tables with coloured bar codes and principal component analysis. Seasonal proportional percentages of total microbat call and feeding buzz and insect call abundance across all landscape variables were compared using coloured pie charts.

Species distribution focused initially upon utilisation intensity determined for each land cover variable by the development of utilisation intensity ranks identified in tables with bar codes. The colour code was identified in order of intensity from red, orange, yellow, and x. In the final sections an attempt was made to develop a visual colour coded representation scheme for determining the functionality of guilds (as pest workers) across the cotton landscape and natural vegetation. In order to better understand the activities of the bat community within that cotton landscape, known foraging patterns of individual species within guilds were fitted to their call activity and then visualised. The colour code combined with fitted foraging patterns is intended to give the cotton industry a quick, intelligible and convincing picture of the importance of bats over cotton landscapes. This code identifies the microbat species together with significant implications for vegetation management in cotton landscapes. Attached to this section is set of column graphs seasonally separating calls and feeding buzzes by land cover variable and species within functional groups.

In the penultimate section graphs were developed utilising land cover variables and guilds, as well as species within guilds or functional groups, to demonstrate a seasonal comparison in presence at percentage of sites across the cultural landscape. Finally a Microbat Species Index was developed utilising a red (highest), orange and yellow colour code to identify seasonal species richness by land cover variable and species within functional groups.

IDENTIFIED LANDSCAPE CATEGORIES

Native vegetation landscape categories A to G

Plate 4.Ai (RGF) or (A) river gum forest (*E. camaldulensis*) lower flood plain, Site Bb summer “Mollee” Note: lippia remediation (right) RGOW upper flood plain

Plate 4.Aii (RGOW) or (B) river gum open woodland (E. *camaldulensis*), Site Ac spring “Nyalla” Carberry Enterprises
Note: green groundcover is Lippia, resulting in large deep holes in the earth contributing to stressed tree condition

Plate 4.Aiii (PB or (C) poplar box (*E. populnea*) open woodland Site Ei autumn “Little Mollee” (fallow cotton field on left)

Plate 4.Aiv (GB) or (D) grey box woodland (*E. pilligaensis*) Site Hi autumn “Cardarga” Carberry Enterprises

Plates 4.Av (MIX) or (E) mixed species woodland - grey box (*E. pilligaensis*), poplar box (*E. populnea*), belah (*Casuarina crista*), and some black wattle (*Acacia excelsa*). Left: Site Co summer “Cardale” “Mollee” entrances; Right: Site Gg summer “Cadarga” Carberry Enterprises

Plate 4.Avi (CP) or (F) cypress pine forest (*Callitris glaucophyll*) & Baradine or dirty gum (*E. chorodada*), Site Gj summer “Cadarga” Carberry Enterprises

Plate 4.Avii (GIT) or (G) grasslands and isolated trees Site Dn autumn “Cardale” Carberry Enterprises

Intensive management landscape categories H to J

Plate 4.Aviii (IC) or (H) irrigated cropping Site Aq summer "Mollee"
Water supply channel left, water in tail drain central field indicates irrigation in progress; fallow field on right, poplar box remnants in background

Plate 4.Aix (WS) or (I) water storage small, surrounded by poplar box Site Hl summer– "Cadarga" Carberry Enterprises

Plate 4.Ax (WS) or (I) water storage large, Site Ha autumn picked cotton on right "Cardale" Carberry Eterprises

Plate 4.Axi (DC) or (J) dryland cropping Site Bs summer - northern dryland cropping upper flood plain, looking south - "Mollee"

Plate 4.Axii (DC) or (J) dryland cropping Site Go summer, southern dryland cropping, looking north - "Cardarga" Carberry Enterprises

CHAPTER 5   LISTENING TO CHANGES ALONG THE NAMOI

A reconstruction of a cotton landscape

Phil Norrie, Picking cotton 2005, ‘Mollee”

Contents

INTRODUCTION

As microbats are insectivorous and in the study area most species are dependent upon bark and a variety of tree hollows for roosting sites, this chapter will examine the landscape changes that may have impacted upon microbat communities in a now intensively managed agricultural landscape This chapter also explores the drivers of the landscape change against the assumptions that

(1) present landscape condition is attributable to past land management practices based on the desire to subdue and conquer, and to create 'useful' landscapes resulting in land degradation; and
(2) present biodiversity condition is attributable to past cotton production's exploitation of land for profit and extensive utilization of pesticides and water, resulting in massive habitat destruction and biodiversity extinction.

5.1 EARLY LANDSCAPE HISTORY

The name 'Namoi', a derivative of the Kamilaroi word *ngama* meaning 'breast' or *ngamaay* meaning 'a variety of acacia trees', is suggestive of a river providing rich nourishment, or supported by a richness of vegetation.

In 1818 John Oxley described the Namoi River as a river lined with trees. Some of the trees he identified can be recognised today as river red gums, casuarinas and angophoras. Oxley described the adjacent alluvial plains as a diverse landscape, ranging from, 'thinly studded with timber' and 'covered with grass', to 'covered with cypress and small brush'.

A run named 'Nurrabry' was taken up in 1834 by the Doyle family, but the township of Narrabri was not proclaimed until 1860. Wee Waa, however, proclaimed in 1847, was one of the first towns on the Namoi River and between 1846-1856 became the centre of all court and legal proceedings in the north west of NSW.

The research area, now situated between the 1901 Narrabri to Wee Waa/Walgett railway line and the Namoi River, was in the late 19th century dissected by Cobb & Co coach routes. Anecdotes suggest that some of the earliest vegetation interventions were associated with activities of bullockies who occupied 100 acre river bank subdivisions along these routes. They were reputed to have "chopped out any emergent saplings that might have competed with grass production" as food for their teams (Killen pers. communication 2005).

The research area is situated within the Parish of Mollee and small northern portions of the Parishes of Boral and Quin, in the County of White and land district of Narrabri. Available Portion plans representing approximately 40% of the Parish of Mollee were examined (Department of Lands, Moree). Drawn between 1895 and 1926, the Portion plans included surveyor's descriptions of vegetation, areas marked 'plain' and 'open plain', as well as large areas marked 'ringbarked' (1901). Continuous swathes of differing groupings of vegetation were drawn across a high proportion of the plans (Attachment 5). These descriptions are included in Table 5.1a.

Table 5.1.a. Vegetation groups, their location and dates of notations on Portion Plans for Parish of Mollee, Country of White (Department of Lands, Moree)

Location in landscape	Date and mixture of vegetation
adjacent to the river	• 1895: open box & gum; belah & wild willow; box, rosewood, apple & gum; • 1913: gum chiefly, some apple & coolibah, marsh mallow and thistles; • 1926: open gum, box & coolibah;
across a flood plain	• 1895: box, gum & apple; box and gum; open box and rosewood; box and oak.
above the flood plain	• 1895: coolibah, brigalow, rosewood; open box; coolibah & rosewood; coolibah; • 1904: thickly timbered box, belah, rosewood and wild willow; box, belah, oak and gum; belt of ti-tree; • 1913:gum & coolibah; open gum • 1915: open coolibah, bibble; dead myall; dead myall and stumps, odd whitewood, coolibah; dibble, coolibah, wilga, whitewood; high bibble; box clump; open box and myall.
along Deadman's creek & /Bessie's swamp	• 1901: open box, belah and gum; thick box, pine & rosewood not rung; very open box & myall; thick box, pine and oak; thick box, pine, gum & rosewood (Ringbarked); thick box, belah, pine & rosewood (Ringbarked) • 1915: open box and myall; box clump;
sandy soils distanced from river	• 1904: gum & box with a few pine and ironbark; belt of ti-tree; box, belah rosewood, wilga, gum & oak; pine, box, ironbark & belah

Of the thirty-seven notations (Attachment 5 Fig. 5A and Table 5.2a), ten described the vegetation as 'open'. Two of these were adjacent to river, one across the flood plain, four above the flood plain and three along Deadmans' Creek and Bessie's swamp (Attachment 5). Five notations described the vegetation as 'thick', one above the flood plain and four along Deadmans' Creek and Bessie's swamp, with 'clumps' marked along Deadmans' Creek and Bessie's swamp.

Set out in Table 5.1b is a list of the vegetation noted on the Portion Plans (Attachment 5). Against these names, the botanical names (where known) have been fitted, together with details of maximum height, soil type and location, season of flower, uses, and status in today's landscape (Carr and Curtis 2000). The smaller species listed as either absent (A) or having an isolated presence (IP) in today's landscape, are all species suitable for fodder or firewood (columns 6 and 7 Table 5.1b).

Table 5.1.b. Vegetation species noted in Portion maps, their biological name, max height of growth, soil type in which it is found, season of flowering, uses and status in the landscape today (Carr & Curtis 2000)

Common name	Botanical name	Height max.	Soil type	Flower	Uses	To day
apple	*Angophora floribunda* (rough barked) ? *Angophora leiocarpa* (smooth- barked)	30m. 30m.	various, usually undulating or beside rivers; sandy soils	winter-summer	occasionally for flooring; some fodder; honey; occasionally for flooring;	VIP A
belah	*Casuarina cristata*	20m.	dry calcareous & stony		excellent firewood; fodder	P
bibble	? bimble *Eucalyptus populnea*	20m.	gravelly soils, alluvial flats			P
box	? Pilliga grey box; (narrow leaved) *Eucalyptus pilligaensis*	25m.	sandy or light alluvial soils		construction, engineering/ farm use; firewood	P
brigalow	*Acacia harpophylla*	25m.	loam & clay	winter – spring & rain	construction, joinery, turnery; firewood; bark for tanning; suckers eaten by sheep	VIP
coolibah	*Eucalyptus coolabah*	20m.	black/grey clay flood plain; sandy alluvial		white ant resistant; firewood; fencing	IP
gum	? river red gum *Eucalyptus camaldulensis* ?	45m.	river flats, dry creeks bed on deep alluvial soil		furniture, construction, engineering; excellent firewood; fencing; charcoal, honey	P
ironbark	? *Eucalyptus creba* (narrow leaved); *E. melanophloia* (silver leaved)	35m. 20m.	stony ridges/ shallow sandy; Sand plains & deep sand over clay, stony ridges on loamy soils		construction, sleepers, fencing, excel firewood; Strong & durable less uses than *E. creba*	IP
myall	*Acacia pendula*	13m.	flood plain, heavy clay	erratic depend on rain	excellent firewood; fodder	A
native willow	(cooba) *Acacia salicina*	20m.	watercourses & alluvial soils	throughout year usually winter	fodder; firewood; (erosion control)	A
oak	? river oak/ she oak *Casuarina cunninghamiana*	30m.	water courses		firewood; some fodder value	IP
pine	*Callitris glaucophylla* (white pine)	20m.	red/brown earths/ shallow soils		termite resistant widely used; oils in perfumery	P
rosewood	(boonery or Western rosewood) *Alectryon oleifolius*	9m.	heavy black soil/ sandy soils with limestone	early Summer	fodder, fences	VIP
ti-tree	? *Melaleuca bracteata* ? *Melaleuca densispicata* (1986 *Leptospermum flaviventris* downstream)	10m	watercourses; discontinuous border around depressions	spring	leaf oils grazed sparingly	A A
white wood	*Atalaya hemiglauca*	9m. clump	alluvial plains	spring-summer	excel. fodder with caution	A
wilga	*Geijera parviflora*	10m	red clays, sands & loans		fodder	IP

KEY: A Absent; VIP Very Isolated Presence; IP Isolated Presence; P Present

5.2 FROM 1919 TO 1960

To understand the changes and their drivers in the study area between 1920 and 2005, interviews were conducted in 2005 with the past and present landowners: Jerry Killen, previous landowner of “Mollee”, Pat Carberry, family member of S. Carberry and Sons, and Alan Goode, manager of “Little Mollee”.

This historical reconstruction commences with events in 1919 and 1924. The first was the post World War I soldier settlement selection of 1,000 acres by Stan Carberry, who named his selection ‘Cadarga’ after the South African Hotel in which he convalesced.

The second was the purchase of 'Mollee' (2,500 acres) by Bill Killen for stock brought from the family property in the Riverina district (Fig. 5.2).

The Carberry and Killen responses on arrival reflected very different approaches to the landscape. The returned soldier with his background of horses in the Wellington district of NSW had drawn a "heavily timbered" selection, on which he set out to grow wheat; the grazier had purchased an open woodland tract of land for his stock. "Stan was known as the mad farmer and Dad known as the mad grazier" (Killen pers. comm. 2005). No wheat had been grown in the area before that date.

Cadarga

'Cadarga' was described by Stan's son Pat (2005) as "…. just green scrub with belah trees and pine trees and he cut his way in off the road when he went out there in his horse and sulky and pitched his tent on the 4th March, his birthday, in 1919. . . They used to bring trainloads of men out there during the weekends to help him clear his land, and then he went through pretty awful seasons, but eventually he had a lot of luck and bought more land. . . . He had a few sheep and he started to grow wheat – he had his horses and his plows and his old fashioned seeders." (Carberry 2005)

Mollee

Given Killen's philosophy of not clearing vegetation on 'Mollee', his 14,000 sheep and 8,000 cattle resulted in the tree vegetation remaining "relatively unchanged" between 1924 and the wool commodity market's collapse in the 1960's (Killen 2005). Grazing pressure in that period may however have been responsible for some of the small shrubby species decline and negligible recruitment indicated in Table 5.1b.

The "relatively unchanged" status on 'Mollee' came at a cost elsewhere in the landscape. A flood in 1954 resulted in the loss of 36 miles of fences on 'Mollee'. The lack of suitable timber for fence posts prompted the purchase of another property towards Coonabarabran to fell ironbark for fence posts. The property was resold after clearing, the stock-piling of approximately 300,000 posts, and the completion of replacement fencing. (Killen 2005)

Other recollections by Killen (2005) of changes in vegetation on 'Mollee' prior to 1960 included:

- Quinine - "Fifty excited people hunting down the last rabbit in a clump of quinines on the edge of the flood plain near the house in 1948/49" marked the eradication of rabbits and the demise of clumps of quinine (*Alstonia constricta*), favourite locations for rabbit burrows.

- Myall trees (*Acacia pendula*) - "Numbers of them. They were bloody ancient, huge. They were all dead - hadn't been ring-barked, hadn't been sawn down or chopped down. They were just lying there, completely dried out. We used to go out in autumn with a truck and get these massive myall tree logs - for about forty years! It was the best firewood because it was almost ashless and burned very hot. There were no other myalls on Mollee." Other myalls noted on the Portion Plans had apparently disappeared from Mollee by the time of this recollection.

- Pine from thick pine stands (*Callitris glaucophylla*) was used for sheep yards.

- Black wattle - isolated thick stands (*Acacia hakeoides*?) – "I don't know whether it was grubs, or the season or what, but they were all big trees. One day you'd go past and they would all be dead."

- Coolibah, carbeen and belah - There were isolated patches of coolibah, and some clumps of carbeen (*Eucalyptus tessellaris*), and in the transition soils, belah (*Casuarina cristata*).

Cadarga, more land and sons

Carberry purchases from the bank added another 500 acres to 'Cadarga', and in 1930 a 1,200 acre river block, 'Nyalla' for grazing (Figs. 5.2 and 5.3). In 1913 the 'Nyalla' area was described as "chiefly gum, some apple and coolibah, marshmallow and thistles" (Attachment 5). A Corriedale sheep stud was established, and with the expertise and advice of a young agronomist, Jim O'Riley, wheat trials were commenced. Carberry went on to win many wheat growing competitions.

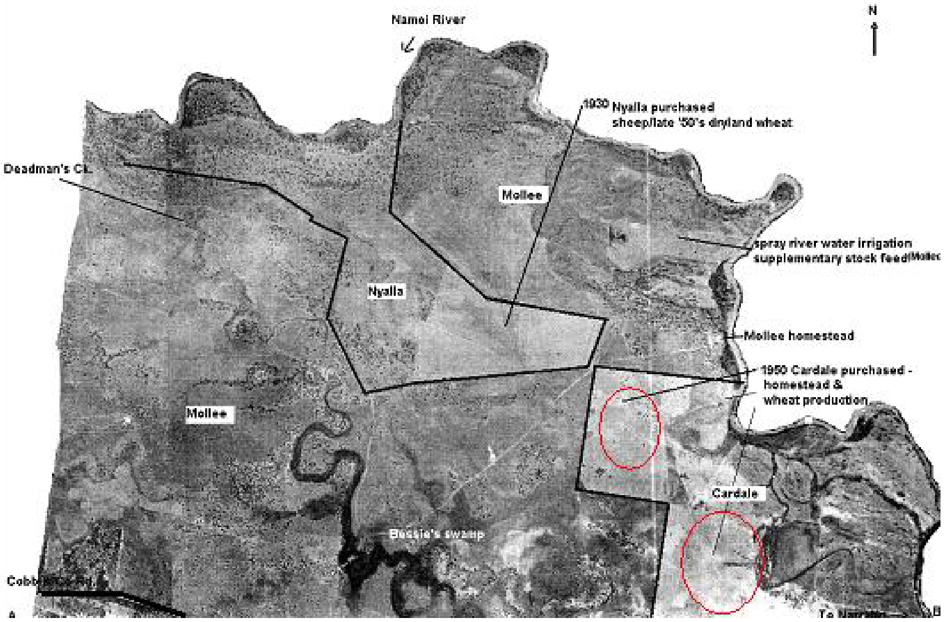


Fig. 5.2. Research area 1962 without Cadarga to the south (north-western section of present Cadarga visible in south-western corner) (Land and Propety Information, 1962). Red circles indicate wheat fields.

In 1950 ‘Cardale’ was added to the Carberry enterprise for son Pat (Fig. 5.2), and the heavy stocking of sheep carried out by the previous owners was converted to wheat production. The vegetation in the vicinity of the two wheat fields circled in Fig 5.2 had previously been described as:

- northern field -“plain; open box” in 1895, and in 1901 “plain open; box clump; coolibah & brigalow; coolibah and rosewood; coolibah”, and
- southern field - “plain; grey soil; box, belar, rosewood, mulga, gum” in 1904.

In the late 1950s the south-eastern section of ‘Nyalla’, described by Pat (2005) as “grazing country with a few bumble trees (*Capparis mitchellii*) that were somewhere between a tree and shrub, and a lot of green rolley-polleys” was also developed into wheat fields. Earlier descriptions of the same area were “level rich loamy soil; dead myall and stumps, odd whitewood and coolibah” in the east (1926), and in the west “open level black clay; dead myall” (1915).

The Namoi

The river during the mid 1940s and ’50s was described as: “trickling most of the time when it was raining and then for a substantial period of time it wouldn’t be running at all – it didn’t have benches like you see today – they weren’t very big and only about a metre from the bed – then there were islands about 6 feet higher – but with a flood there would be massive bank slumping and of course the river would change quite dramatically - and big trees would go in and the stream ripped up. But the major change has been in just normal flow times. There was a lot of weed, ribbon weed, ribbons 15-20 feet long - the river basically clear unless it was a start of an event – and if you were going fishing you’d wander along the high bank and look down and you could see the fish and that’s where you went fishing. All the aquatic growth was there then, and mussels and stuff.” (Killen 2005)

5.3 1960 TO 1974

Wool market collapse

For the Killens on ‘Mollee’ the collapse of the wool market in the 1960s forced a dramatic change in focus from a reduction in wool production and sheep numbers to the acquisition of farming skills. “Mum had died in 1958 and Dad retired and left in 1962…. I came back from Queensland - and my brothers and I started to farm! So that was about 1964/65 and we had plowed a lot of country by 1967! Then with the 1967 drought, the wheat crops went tits up! The sixties were a time of massive change!” (Killen 2005). A comparison of 1962 and 1972 aerial photographs (Figs 5.2 and 5.3) illustrate this dramatic landscape change.

For the Carberrys the move during the 1960s away from broad-wool production - at its peak 5,000 sheep - was activated predominantly by the change to irrigation cropping, and in the 1970s to cattle production.

Early flood irrigation

Although prior to 1964 an area of flood plain on ‘Mollee’ had been established utilising river water and spray irrigation to grow supplementary stock feed, water availability from the newly completed Keepit Dam enabled the development of more extensive irrigation cropping. In 1964/65 80 hectares immediately above the flood plain were ‘cleared’ and leveled, and a river pump, water storage and infrastructure established. Killens commenced growing irrigated cotton together with a variety of crops including potatoes, and – in one year - flowers. Parts of the cleared area had been described in 1915 as "level rich loamy soil, dead myall and stumps; odd whitewood, coolibah", and in 1926 as "chiefly gum".

The development of the 'Nyalla' and some of the 'Cardale' wheat fields into cotton fields, although also prompted by the availability of river water licenses, was primarily stimulated by a visit in 1961 to Carberry's small irrigated lucerne block by one of the American cotton growers instrumental in introducing cotton to the district. After initially "sitting on our hands for a couple of years", when it appeared the water license allocation was nearing completion, the Carberrys "grabbed a couple…. and then stood down in the middle of the field and thought, we should be doing something". So, the blocks on 'Nyalla' and 'Cardale' were surveyed and developed by the Department of Water Resources. The small-field design was abandoned, large blocks developed by a local dozer driver, and two pumps, water supply channels and infrastructure installed. Cotton production was commenced by a share-farmer and a financial backer. For two years the Carberrys watched closely, then "sacked" the share-farmer and commenced growing cotton in 1967/68.

1967 Drought

Accompanying the 1967 drought and the consequent failure of dryland wheat crops on Mollee in 1967 and 1968, two bores were drilled away from the river and two more areas prepared for irrigated cropping. Of the farming land adjacent to the bore furthest from the river Killen (2005) commented ". . . We couldn't grow bloody crops because we didn't know about gypsum and all those things. But since Carberrys bought it, they actually got into gypsum. So that country there, that they farm now, was just called a clay pan. There were very few trees, scattered box, a lot of daisy and neverfail and pigwort and all that sort of stuff."

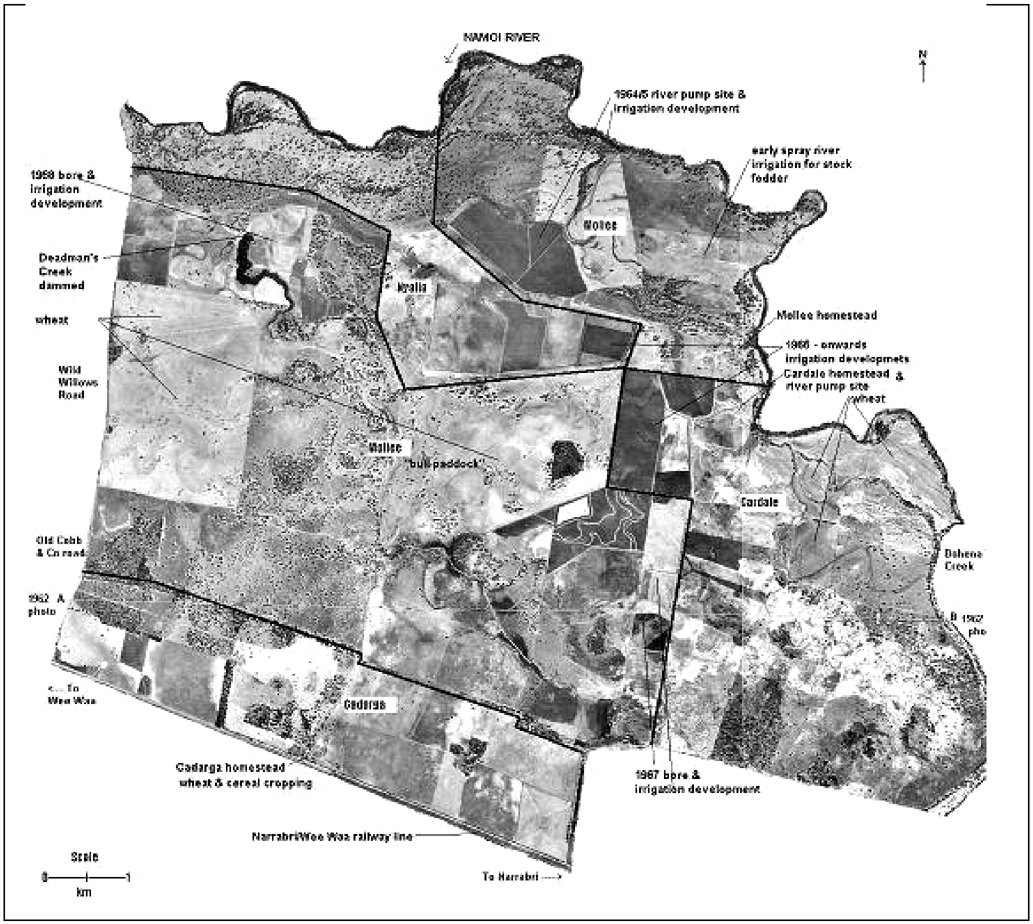


Fig 5.3. Research area 5.11.1972 highlighting changes since 1962. Note A-B line southern extremity of 1962 image) (Aerial photograph Land & Property Information, 1972)

There was a flood in 1971, and *Heliothis armigera* a major cotton pest moth indigenous to Australia, arrived from Queensland in 1973, decimated crops and initiated the high usage of broad-spectrum chemicals.

5.4 1974 TO THE PRESENT

Sale of 'Mollee' – new ownership

'Mollee' was subdivided and sold in 1974 to three families, the Norries ('Mollee' house block 1,282 acres); the Davidsons ('Little Mollee' 1,100 acres) and the Carberrys ('Wilga' and 'Green Trees' 4,000 acres). Thereafter 'Cadarga', 'Nyalla', 'Cardale', 'Wilga' and 'Green Trees' was managed as one enterprise, S. Carberry & Sons (Fig. 5.4a).

The Norries and Davidsons brought with them 20,000 Coriedale sheep and 150 cows to stock the ‘Mollee’ and ‘Little Mollee’ 2,382 acres. The sheep were sold after about three years, and the cattle herd increased to around 300, but on the purchase of another property in 1988 reduced to around 250, where it has remained.

During the mid 1970s the Carberry grazing enterprise shifted from sheep to purebred Herefords and a herd of Herefords and Santa Gertrudis cross. A small private feedlot was established that utilised their own production of oats and cotton seed hulls as well as dryland crops for fodder.

Floods - 1974 and 1976

There was a flood in 1974, and two in 1976. The 1976 flood movement of the river pump site at ‘Mollee’ and the destruction of spray irrigation infrastructure necessitated the relocation of the pump station and supply channel infrastructure. The Norries reconfigured the 80ha irrigation area, added another small field (107ha total), and continued growing irrigated crops, primarily soya beans together with sunflowers, sorghum, wheat and barley. They also commenced the development of the ‘bull paddock’ well away from the river, in the centre of the study area (Fig. 5.4). Between 1978 and 1988 the 273ha ‘bull paddock’ described as “very open box and myall” in 1901, and regarded by Norrie (2005) “of low grazing value’ consisting of “some stands of trees but mainly scattered trees”, became farming blocks, and eventually 11 cotton fields (Fig 5.4a).

Killen (2005) commented “the Norries and Carberrys farmed paddocks we regarded as too bloody swampy to be good grazing blocks – it was virtually dead flat – what we used to call swamps – the water course was very shallow. They were so tightly clayed underneath that the water couldn’t get out and if you had a wet season the water would be there for six and eight months at a time. And the bloody mosquitoes - that’s what I remember – and we used to curse – because the wool would be buggered up. You couldn’t drive a car around. You couldn’t even use a horse and sulky in a wet season. Every day you’d be out dagging sheep on horse back!”

From its commencement in 1966, irrigated cotton production had continued to expand across the Carberry properties. The Killen irrigation fields around the 1967 bore, "only good for holding water" (Carberry 2005), were transformed into water storages between 1974 and 1980, and the adjacent paddocks have now become Carberry's highest yielding cotton fields.

1980s second wave of irrigated cotton production – commodity prices, management and intergenerational change, droughts and floods

The 1980s witnessed another wave of interest in cotton production, primarily contingent upon the introduction of module builders that facilitated cotton production at greater distances from the cotton gin (Norrie 2005). The coincidental introduction of four-row pickers replacing two-row pickers accelerated picking and consequently lowered cotton vulnerability to rain and reductions in quality.

Mollee On 'Mollee" in 1978, 1980 and with the purchase of a dozer again in 1981, water storage and associated infrastructure construction was undertaken to hold and deliver the two sources of water around the property. In 1981 two more bores were drilled, one in the 'bull paddock' development, the other alongside the old irrigation blocks (Fig.5.4.a) (Norrie 2005).

With the commodity prices for soya beans continuing to decline, Norries reassessed crop production and commenced growing cotton on 250 acres in 1981, followed in 1982 on 400 acres. The drought in 1982/83 prompted construction of a second water storage, to collect surface runoff along Deadman's Creek, irrigation tail waters from the bull paddock irrigation fields and eventually water from a bore drilled in 1993-4. In 1998 a 53ha field (Field 15) adjacent to the new water storage was cleared of scattered and open woodland poplar box and some dense cypress pine and prepared for irrigation.

In 2003 the encroachment onto river plain grazing country by lippia forced a redirection from wheat production to cattle fodder production. Thus a nearby property 'Alawa' was purchased for dryland cereal cropping and cattle production, this expansion being accommodated by the return of a son (Norrie 2005).

Little Mollee 1982 saw changes on ‘Little Mollee’ with the arrival of a new Manager, Alan Goode, who “learned a lot, fast, about growing cotton”. He grew the first ‘Little Mollee’ cotton crop (48ha) under an overhead irrigation spray centre pivot using water from the 1968 bore. In 1982/3, with the assistance of the Departments of Soil Conservation and Water Resources, Deadman’s Creek was dammed and the banks planted with trees to provide both a water storage and a riverine vegetation corridor. Drought followed in 1983/4 (Goode 2005).

On ‘Little Mollee’ in the following years more land was cleared of scattered and in places quite dense box trees (“box clump; open box and myall” 1915), adding eventually three more centre pivots and another 144ha of cleared but not leveled land available for overhead sprinkler irrigation cotton production. In 1993 a bore was drilled adjacent to fields that in 1988 were covered by a new lateral overhead spray.

Land suitable for cattle grazing had been reduced to two areas. One was a paddock of scattered poplar box (1915 open box and myall) along the Deadman’s Creek water course above the dam, and the other was a paddock of open river gum woodland flood plain (1926 open gum, box and coolibah; black soil). With the lippia invasion of the river red gum flood plain, the 100 cows and their progeny of 1982 have been reduced to 15 cows, their calves and a few steers in 2005 (Goode 2005).

Carberry and Sons The Carberry enterprise during the mid 1980’s underwent its second generational expansion with the addition of two grandsons. Thus Pat and son Michael concentrated on irrigated cotton production, and Bill and son Andrew on dryland cereal and cattle production. The ‘Wilga’ irrigation development of fields previously cleared by Killens, was completed, followed in the late 1990’s-2003, by the ‘Green Trees’ irrigation development. ‘Green Trees’ was a continuation of what the Killen’s regarded as swamp. “I don’t know why it was ever called ‘Green Trees’ because there were no trees on it” (Carberry 2005).

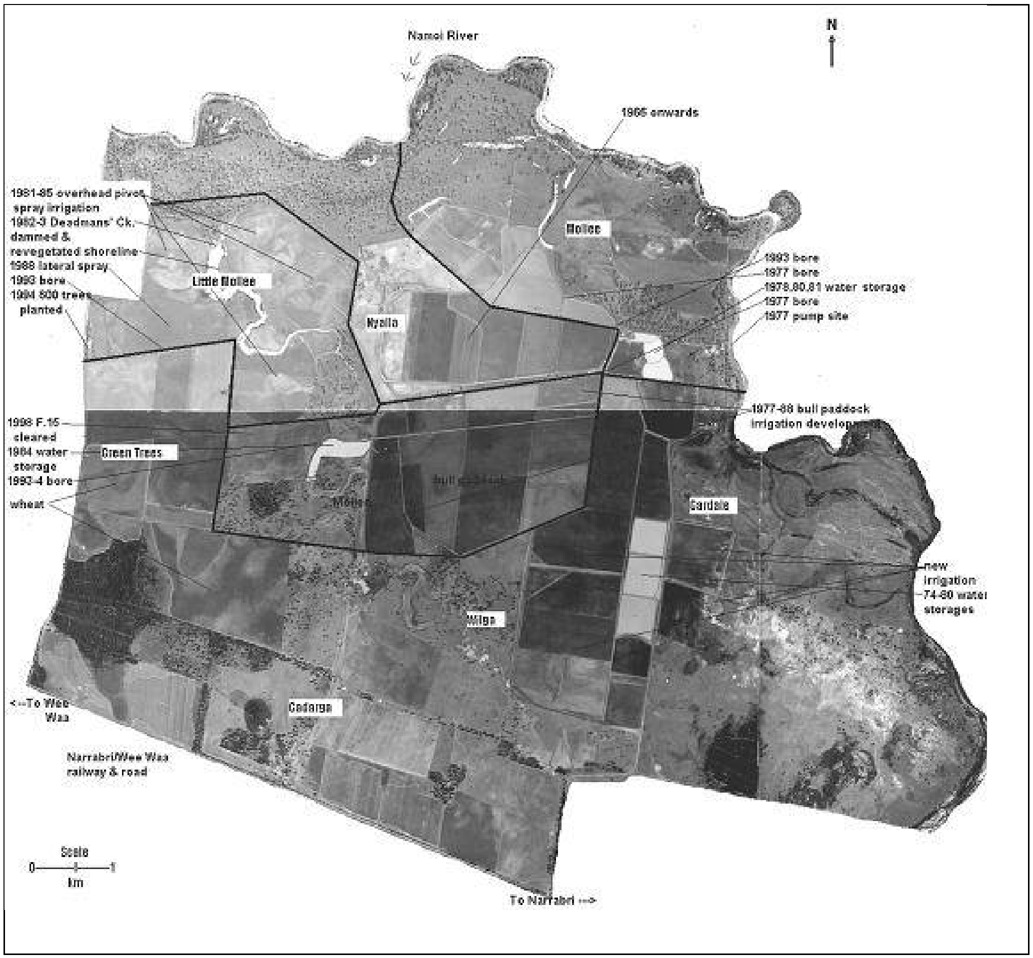


Fig. 5.4.a. Research area 13.12.1998 highlighting landscape changes since 1972. Properties ‘Cadarga’, ‘Nyalla’, ‘Cardale’, ‘Wilga’ & ‘Green Trees’ managed as one enterprise S. Carberry & Sons. Irrigated cropping areas outlined in red. (Aerial photograph Land and Property Information, 1998)

Droughts occurred during 1993-94, and 2002-04, and floods occurred in 1998-99, 2000-01 and 2004-05.

Current irrigated cropping production

The current status of production development across the study area can be seen in the 2003 aerial photographs in Fig. 5.4b.

Along with the production of the largest cotton crop on ‘Mollee’ in 1988 (800 acres or 324 ha), came the realisation of the difficulty in keeping water supplied to such a large crop. Consequently crops in subsequent years were reduced to 700-750 acres (284-304 ha), and again to 600 acres (243ha) in 2003/04. ‘Mollee’ currently has 1,180 acres (477ha) developed for irrigation production (Norrie 2005).

Fig. 5.4.b. Research area 18.07.2003 showing changes since 1998. (Aerial photograph Land and Property Information, 2003) Current property boundaries marked with interrupted line.

‘Little Mollee’ was purchased in 2000 by Cotton Seed Distributors, the commercial arm of CSIRO. It is now operated as a cotton-seed enterprise, for testing, assessing and producing cotton variety nursery lines developed by CSIRO. Alan Goode was retained as the Manager. ‘Little Mollee’ now has 660ac (267 ha) of land developed for irrigation production (Goode 2005).

Carberrys initially grew about 400ac of cotton a year, increased it to 500 then 600 acres, and in 2005 grew 1,000 acres (405ha). The Carberry irrigation enterprise consists of the 1960/70’s developments on ‘Nyalla’ (145ha) and ‘Cardale’ (59ha) increased to 165ha, the 1970-80's development of the 'Wilga' (218ha) fields, together with the late 1990's-2002 development of the 'Green Trees' (244ha) fields. Carberry's currently have approximately 2,000 acres (809ha) of land developed for irrigation production.

The Carberry cattle enterprise produces 500 to 600 cattle a year through their feedlot over winter. Weaner calves are sold for the Woolworths market after 70 days in the feedlot, and bullocks for the European Union overseas market after 100 days (Carberry 2005).

A lippia remediation programme of clearing dead and fallen timber followed by cycles of plowing and cropping aimed at eventually replanting pasture grasses, was commenced in 2002 across approximately 450 acres of the 'Mollee' river red gum flood plain country (Fig. 5.5b). On the Carberry enterprise lippia remediation commenced in 2004 by plowing and planting wheat across approximately 225 acres of 'Cardale's' floodplain grasslands (Fig. 5.5b) (Norrie and Carberry 2005).

Vegetation cleared since 1980

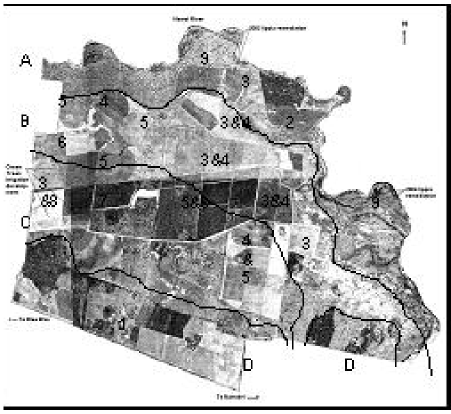
Vegetation cleared and developed for irrigated cropping between 1980 and 2004 was 1,155ha and included:

Property	1980's ha	1990's ha	2000's ha	TOTAL ha
Mollee	317	53		370
Little Mollee	217			217
Carberry enterprise	106	218	244	568
TOTAL	640	271	244	1155

5.5 LOOKING BACK

To examine the process of landscape change the study area was roughly divided into four categories based on geomorphologic and soil characteristics and vegetation type (Figs. 5.5a and b, Table 5.5). Category (A) is defined by the two terraces forming the flood plain adjacent to the river, (B) is defined by a third terrace forming rich flats well above the river, (C) is defined by an ancient serpentine stream system clearly seen in Fig. 5.2 that now consists of swamps over clay soils with some interspersing sandy ridges, and (D) is defined by the predominantly sandy rises and lighter soils in the south.

For these categories a time-table of change across the study area has been set out in Fig. 5.5a and Table 5.5. Numbers 1 to 9 and column 3 to 8 respectively identify the changes from the early sheep grazing and clearing for wheat in 1920s (1 and column 3) to an intensively managed landscape focused upon irrigated cropping and lippia management (9 and column 8) in 2003. This timetable (Table 5.6) has been juxtaposed against the vegetation described in the Portion Plans 5.1a.



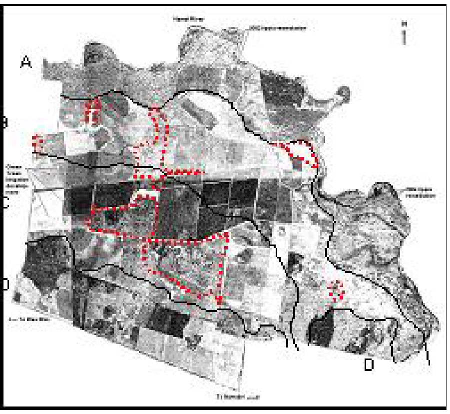


Fig. 5.5.a. Generalised geomorphologic/vegetation/soil categories (A-D) and times of vegetation change and development (1-9) between 1920 and 2004

Fig. 5.5.b. Generalised geomorphologic/vegetation/soil categories (A-D) and remaining vegetation in B and C; Dotted outlined areas identifying remaining vegetation remnants in areas B and C

KEY
(A) river flood plain 1st & 2nd terraces, some braided channels;
(B) 3rd terrace fertile flats;
(C) ancient serpentine stream system – swamps (Deadman's Creek/Bessie's Swamp) with some sandy rises;
(D) predominantly lighter soils and higher sandy rises

Across the two terraces forming the immediate flood plain (A), grazing and stock access to the river has been continuous. Small areas utilised for irrigated fodder production before 1960, during 1970s were converted and extended to dryland cropping of wheat. The small areas used in 1960s for irrigated cropping were abandoned towards the end of the decade. Grazing has resulted in areas of both mixed older aged remnants, and very old senescing trees with little or no recruitment. Many have invasions of Nagoora burr and now have a groundcover of lippia, both corollaries of flooding in 1998. A 2003 Vegetation Presence score, from (0) absent to (5) healthy presence, has been given for the species noted in the Portion Plans (Table 5.5): gum (river gum 4 - but stressed), coolibah (1- isolated clump), apple (0 - two trees), box (0), belah (0) and wild willow (0).

Table 5.5. Timetable of changes in vegetation type and management practice across the study area, 1920-2003 (Killen, Carberry, Norrie & Goode 2005)

Landscape element description (properties)	**Early Portion Plan soil & vegetation description (number of recordings) west to east**	**1920/ 1960**	**1960s**	**1970s**	**1980s**	**1990s**	**2000/04 present**
A **Immediate flood plain –** 1st & 2nd terraces (Little Mollee, Nyalla, Mollee, Cardale)	**North**: black soil; rich black soil across shallow flood channels; open gum (2), box, coolibah (2); , some apple, marsh mallow & thistles; **North/east**: gum & box, belah & wild willow **East**: low flooded country; box (2), gum, apple, rosewood, oak;	**G sheep** small early IC for stock	**G** cattle **64/65 IC cropping, small IC/stock**	**G** cattle **DC** wheat	**G** cattle DC wheat	**G** cattle DC wheat	G Reduced G Potential - Lippia management DC programme
B **Higher flats** 3rd terrace (Little Mollee, Nyalla, Mollee, Cardale)	**West**: box open & clump, myall, dead myall (2), high bibble (2), chiefly gum, open coolibah(2), wilga, whitewood; **Centre**: level rich loamy soil, plain; open level black clay; dead myall & stumps, odd whitewood, coolibah; **East**: plain (2); coolibah (4), open box (3), rosewood (3), brigalow (2), apple, gum; **South-east**: open plain, red soil & sodded country; grey soil; belt of ti tree, box, belah, rosewood, wilga, gum, oak;	**G sheep** **DC** wheat bet. 30's & 50's Nyalla, Cardale	**Grazing to DC wheat** Some DC to IC Cotton + other crops - **1967 drought**	**DC to IC** vegetation clearing bores, pumps, water storages, infra-structure	**IC** vegetation clearing bores, pumps, water storages, infra-structure	**IC**	**IC**
C **Ancient serpentine stream/ swamps, sandy ridges** (Green Trees, Mollee, Wilga)	**West**: swamps; box open & thick, pine, rosewood, not rung; **West and centre**: swamp; belah (2), gum; box very open & thick, myall, rosewood;	**G sheep**	**G** cattle **G to DC**	**G** **DC to IC,** DC wheat	G **DC to IC,** DC wheat	**IC** G cattle, DC wheat	**IC** **DC wheat (production creep)** G cattle
D **Predominantly sandy rises** (Cadarga, and southern Green Trees and Wilga)	**West**: ringbarked (2); thick box (2), pine (2), rosewood (2), gum, belah; **Centre**: plain (2); thick box, pine, oak; **East**: pine, box, ironbark, belah. **Southern portions** of this area – no available Portion Plans	Clearing for **DC wheat** & sheep	DC& pasture, wheat & cattle	DC wheat, cattle fodder, cattle feedlot	DC wheat, cattle fodder, cattle feedlot	DC wheat, cattle fodder, cattle feedlot	DC/pasture wheat, cattle fodder, cattle feedlot

KEY:
(**G**) grazing; (**DC**) dryland cropping; (**IC**) irrigated cropping; **Font size** and boldness indicates variations in intensity
Fill colour:
(**full fill**) little change;
(**back slash**) grazing to dryland cropping; (**slash**) grazing and dryland cropping;
(**vertical**) dryland cropping to irrigated cropping;
(**horizontal light**) dryland cropping to total irrigated cropping;
(**horizontal dark**) total irrigated cropping.

Across the high flats (B), early sheep grazing changed to wheat production in the 1960s, some of which was converted to irrigated cropping in 1960s, 70s and then 1980s. This area is now almost totally utilised for irrigated cropping. The remaining native vegetation is restricted to small isolated remnants of old poplar box lacking recruitment and diversity, and a narrow corridor of recently planted river red gums lining the water storage along Deadman's creek. These remaining remnants are outlined in Fig. 5.5.d. The 2003 Vegetation Presence scores are: box (3 - isolated stands), belah (3), wilga (1), ti-tree (1), gum (0), myall (0), bibble?, coolibah (0), whitewood (0), brigalow (0), rosewood (0), apple (0), and oak (0).

Covering an ancient serpentine stream system much of area (C) was swampy. Utilisation for early sheep grazing until 1960s, was converted to cattle production (bull paddock), and has since 1950s in the east, the 1960s across the area, and 2003 in the west, been continuously developed to cropping and then to irrigated cropping. Although a drain was constructed through much of the swampy area in the 1970s, the remaining areas of remnant vegetation outlined in Fig. 5.5.b, are in swampy soils or on sandy ridges. The 2003 Vegetation Presence scores are: open box (4), pine (2), thick box (0 – now very open woodland or scattered trees), belah (1), rosewood (0), gum (0) and myall (0).

Although the first extensive clearing occurred in the lighter soils to the south (D) care was taken to leave vegetation for stock shelter at corners of adjoining paddocks surrounding a bore. Other remnants have been left across this section of the study area and little change has occurred in the areas of vegetation since the 1972 aerial photographs (Fig 5.4.). The 2003 Vegetation presence scores are: pine (5), oak (belah - 3), thick box (2), gum (2), rosewood (0) and iron bark (0).

5.6 CONCLUSION

It has been shown in the study area that the swathe of irrigated cropping across the present-day landscape is the result of alterations over 80 and 100 years, alterations triggered by events such as changed commodity prices, family succession and property ownership as well as droughts and floods and water availability and new technological innovations. Past alterations were undertaken with the knowledge of the day, an underlying creative desire to “make something out of nothing”, and no ill intent towards the environment.

The landscape change has been shown nonetheless to have resulted in a dramatic decline in both the extent and diversity of native vegetation. Up to the present time the emphasis across this landscape has been upon production sustainability with an increasing awareness of and attention to environmental concerns though predominantly within production management practices. These practices have included the adoption of, Best Management Practices, Integrated Pest Management, water use efficiency, river bank fencing (‘Mollee’), wetland trials for the bioremediation of chemicals from tail waters

(‘Mollee’), planting 800 indigenous trees and shrubs around the house and workshop and along Deadman’s Creek water storage (‘Little Mollee’), replacement of roadside exotic poplars (*Populus*) with indigenous trees and schrubs near the ‘Cardale’ homestead, and the joint support for this bats, cotton and native vegetation project.

“Production creep” into vegetation remnants is however still continuing, and there are major shifts taking place. The adoption of GM cotton will activate changes in insect populations, their predators and management, and the exotic highly debilitating groundcover, lippia, threatens the existence of river red gum communities, crucial elements of ecosystem health.

A close examination of the aerial photographs between 1972 and 2003 reveals the continuous presence of some trees. But these now mature and very old trees are showing signs of senescence or are slowly dying and there is little or no recruitment. This raises major concerns for the sustainability of any community of tree hollow dependant fauna, including microbats. It would seem the time gap in the recruitment of trees of around 100-150 years, will be an essential factor in the survival of hollow dependent species such as microbats, a fact that has so far not been considered an issue. The next chapters will present evidence to change that perception. Microbats do matter. There can be no sustainability in the cotton landscape without microbats, as microbats have been and remain an essential element of the region’s biodiversity. Like all other species being similarly affected, microbats are an indicator of the health of the system. Although insects may be present in a landscape, a diversity of bat species and their abundance is not only dependant upon a diverse insect food source determined by the composition and structure of native vegetation remnants but also on a continuing range of tree hollow roosting sites varying in size, shape, aspect, height and tree species. A reduction in the health of a system results in a reduction in the diversity and abundance of a bat community.

This glimpse into the landscape history has shown profound and continuing changes in a natural landscape, now metamorphosed into a cultural landscape. It is nevertheless still diverse, vegetated and contains many natural elements, including bats. Can vegetation remnants and their ecosystem service to cotton production become the next major creative challenge to change “something of little value” into something of recognised and applauded economic, environmental and social value? Can this changing landscape continue to provide essential habitat for a community of microbats?

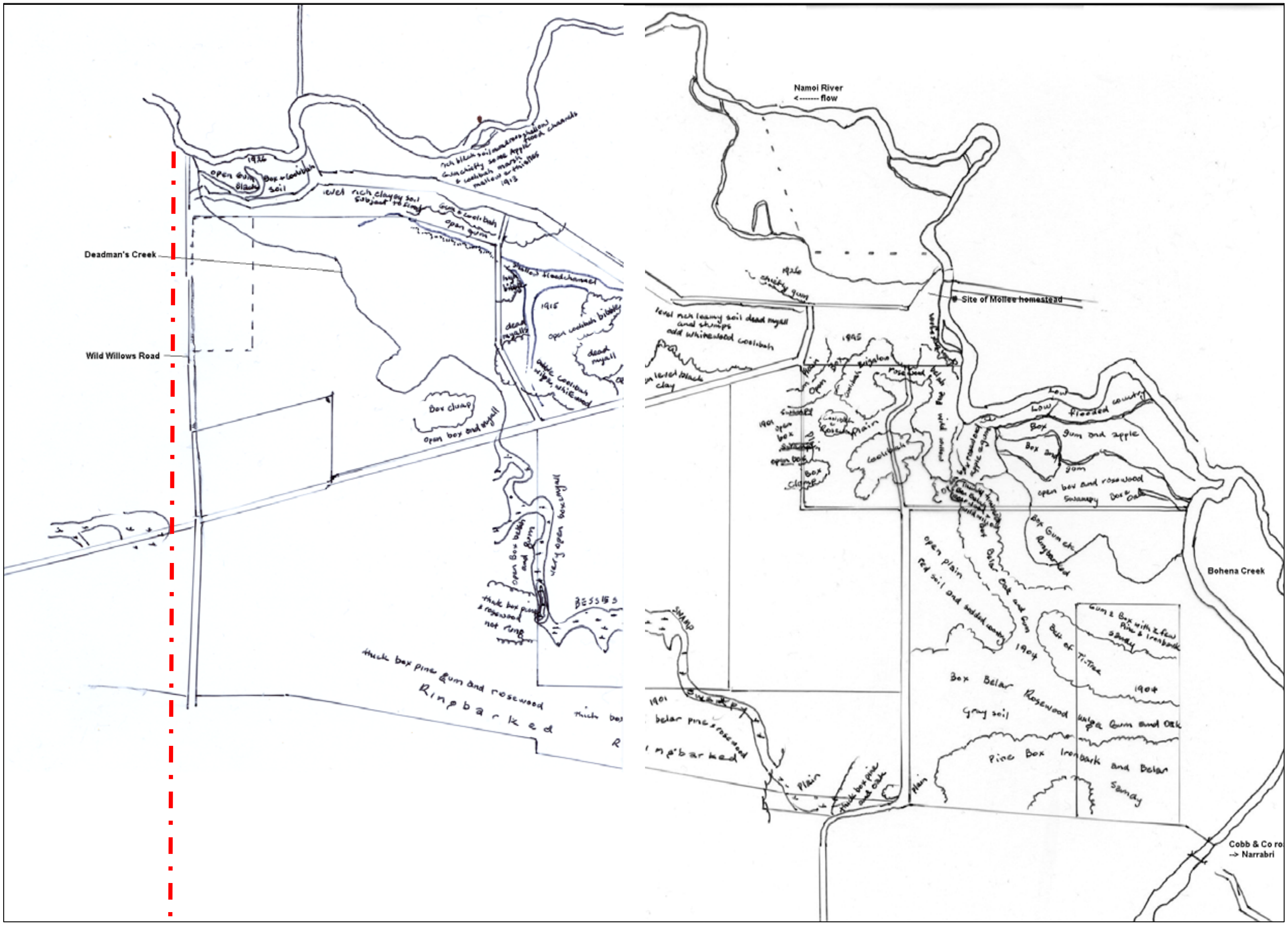


Fig. 5.A Compilation of surveyor's notes on available Portion Plans, Parish of Mollee, County of White, drawn between 1895 and 1926 – (the northern section of research area Figs. 5.1., 5.2., 5.3. & 5.4.) Surveyor's notations include vegetation type, and soil and landscape descriptions (gap down centre is due to scanning limitation

CHAPTER 6.1 MICROBAT DIVERSITY

Chalinolobus gouldii (Gould's wattled)
(black morph)

Mormopterus sp. 3 (inland freetail)

Chalinolobus morio (chocolate wattled)
(three lactating females captured)

Scotorepens balstoni (inland broadnosed)

Nyctophilus gouldi (Gould's longeared)
(photograph J. Bauer 2003)

Nyctophilus timoriensis (greater longeared)
(Vulnerable)

Contents

INTRODUCTION

The diversity of species within particular groups and families of animals is often utilised as a representative value for biodiversity. Such assessments are highly influenced by sampling intensity, sampling sites and the seasonal timing of sampling. This chapter examines how sampling intensity, duration and season affect the diversity of the examined groups. It will establish the first comprehensive bench-mark of bat diversity and community structure for the region of the study and its cotton landscape. This chapter will also expand knowledge of the bat community - so far very poorly understood - in the study area.

6.1.1 AN EXPANDED LIST OF SPECIES

Identification of species using ultrasound echolocation technologies

Of the 13,600 total files recorded during the four landscape surveys, 1,736 microbat calls were recorded during the SSA03/04 seasonal surveys, and 933 unsorted microbat and insect calls were recorded during the EA03 survey. The 1,736 microbat calls from the SSA03/04 were composed of 605 calls in spring, 619 calls in summer and 512 calls in autumn. Details of the four surveys are set out in Table 6.1a. Microbat calls not identified to species level numbered 65 in spring, 57 in summer, and 51 in autumn.

Table 6.1.a Landscape scale microbat ultrasound echolocation activity surveys conducted in the project area 2003/04.

Anabat Landscape Survey Time	Number of nights sampled	Number of sites sampled	Total number files recorded *	Number of microbat calls	Number of insect calls
AE03 - Autumn (20-26 April 2003; post defoliation and picking)	7	102	1,050	933 * (includes other calls)	?
SSA03/04 - Spring (10-30 November 2003; 5-7 leaf stage)	8	64 #	3,843	605	100
SSA03/04 - Summer (28 Feb - 8 March 2004; full flower prior cut-out)	8	64 #	5,450	619	222
SSA03/04 - Autumn (8 –16 May 2004; immed. post defoliation & picking)	8	64 #	3,257	512	121
TOTAL	31	294 site visits **	13,600	933 mixed 1,736 bat	443

* includes all microbat calls (1pulse and above), insect stridation and ultrasound calls, and interference.
** many of the AE03 survey sample sites were retained for the SSA03/04 seasonal surveys.
\# SSA03/04 seasonal surveys sampled the same 64 sites.

Species richness

Eleven species and one genus (*Nyctophilus)* were confidently identified by the analysis of the ultrasound echolocation call data for the four landscape surveys. The identification of six other species was less certain: one is regarded as "probable", two as "possible", and three others are regarded as "possible but unlikely" (Table 6.1b).

Table 6.1.b Microbat species identified during four Anabat surveys 2003/04 (AE03 and SSA03/04)

Scientific name (Family and species)	**Common name**	**EA 2003 (a) +SSA 2003/04 Surveys (b)**
Emballonuridae (Sheathtail bats)		
Saccolaimus flaviventris	yellow-bellied sheathtail bat	confident
Vespertilionidae (Evening bats)		
Chalinolobus dwyeri (vulnerable 4/4/01)	large-eared pied bat	possible/unlikely
Chalinolobus gouldii	Gould's wattled bat	confident
Chalinolobus morio	chocolate wattled bat	confident
Chalinolobus picatus	little pied bat	confident
Miniopterus schreibersii	large bentwing bat	possible/unlikely
Scotorepens balstoni	inland broadnosed bat	confident
Scotorepens greyii	little broadnosed bat	confident
Nyctophilus spp.	Longeared bat	*N.* spp conf.
Vespadelus darlingtoni	large forest bat	probable
Vespadelus regulus	southern forest bat	possible
Vespadelus troughtani	eastern cave bat	possible
Vespadelus vulturnus	little forest bat	confident
Molossidae (Freetail bat)		
Mormopterus beccarii	Beccarii's freetail bat	possible/unlikely
Mormopterus sp. 2	eastern freetail bat	confident
Mormopterus planiceps (small penis) sp. 3	inland freetail bat	confident
Mormopterus planiceps (large penis) sp. 4	southern freetail bat	confident
Tadarida australis	white-striped freetail bat	confident
Total number - species		**14 spp. +1 genus** (11 conf., 1 prob., 2 pos.) **+** (3 spp. pos/unlikely)

KEY
EA03 + SSA03/04 Anabat surveys: 20 minutes recording at 102 sites (Exploratory Autumn), and 64 sites (SSA 2003/04 spring, summer & autumn seasonal) sites over seven & eight nights respectively;
(a) analysed using: Reinhold *et al*. 2001, Herr 1995, Caddle & Lumsden 1997, de Oliveira 1998, Corben & O'Farrell 1999, Richards pers. com. 2000.
(b) analysed using: predominantly Pennay *et al*. 2004, Caddle & Lumsden 1997, de Oliveira 1998, Corben & O'Farrell 1999. 2000, and Reinhold *et al*. 2001.

Although the calls of members of the *Nyctophilus* genus were not identifiable using Anabat technologies, evidence of the close proximity of *Nyctophilus geoffroyi* was provided early in the study by the recovery of a dead *N. geoffroyi* from a *Helicoverpa armigera* pheromone trap. As *H. armigera* is one of the major cotton pest moth species, female pheromone traps attracting male *H. armigera* provide data on population fluctuations throughout the cotton season. The trap, used by Cotton Cooperative

Research Corporation researchers was located adjacent to both a cotton field and the river on a property adjoining the study area but on the opposite side of the river.

Identification of species using capture in harp traps

Forty bats were captured, the capture results reflecting the trap site ratings for capture-degree-of-difficulty or capture-potential (Fig. 6.1a). Twenty-four were captured at cypress pine (CP) sites, ten at river red gum (RGF) sites, and six at the mixed spp. sites (MIX). No bats were captured at the first trapping location, poplar box/grey box (PB) isolated remnant sites, or at the fourth trapping location, water storage (WS) sites (Table 6.1c).

Species richness

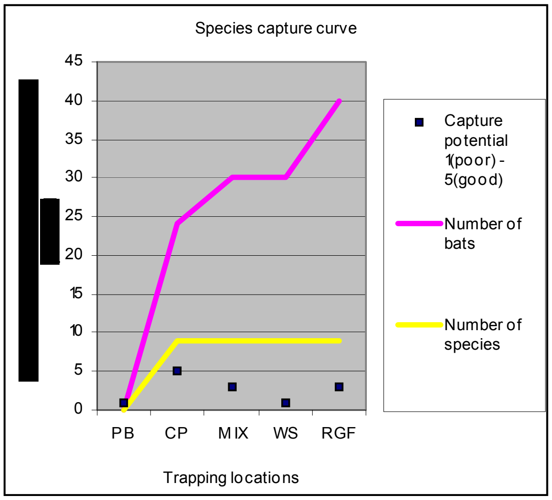
After examination, measurement and analysis of the recorded release calls thirty nine of the forty bats captured were confidently identified into nine species. The remaining bat was identified to genus level only (*Scotorepens* spp.) (Table 6.1).

Table 6.1.c. Microbat species identified, numbers of bats and trapping sites - Capture Survey Spring 2003
Identified using: Churchill 1998 (parameters of known distribution range, forearm length, weight, description, photograph and release calls – (verification by Pennay pers. comm. 2004).

Microbat species	**PB**	**CP**	**WS**	**MIX**	**RGF**	**Total bats**
Vespertilionidae (Evening bats)						
Chalinolobus gouldi		1*				1
Chalinilobus morio		4			10**	14
Scotorepens balstoni		2				2
Scotorepens greyii		4		1		5
Scotorepens spp.?		1				1
Nyctophilus geoffroyi #		3				3
Nyctophilus gouldi #		1		1		2
Nyctophilus timoriensis **V** #		1				1
Vespadelus vulturnus		5		4		9
Mollossidae (Freetail bats)						
Mormopterus sp 3		2				2
Total bats	**0**	**24**	**0**	**6**	**10**	**40**
Total species	0	9	0	3	1	9
Accumulative total species	0	9	9	9	9	9

KEY
* black morph
** includes three lactating females and five sub-adult males
# not identified to spp. using Anabat technologies
V Vulnerable status (NSW Threatened Species

The twenty-four bats captured at the cypress pine sites represented nine species - a high species richness. Although bats continued to be captured after the cypress pine site (CP) (Fig. 6.1a and Table 6.1c), species richness did not increase.



KEY

Native vegetation categories:

(RGF) river red gum forest/woodland adjacent to river;

(PB) poplar box isolated small group;

(MIX) mixed remnant poplar box, grey box & belah;

(CP) cypress pine;

Intense management categories:

(WS) water storage.

Fig. 6.1.a. Species capture curve showing additional microbats captured with increasing number of trap locations

Status

Although the distribution "throughout temperate southern Australia", for *Nyctophilus timoriensis* was regarded as "possibly unchanged" (Duncan *et al.* 1999), a revision of this taxon revealed three species with unclear allopatric distributions (Duncan *et al.* 1999). The status of *Nyctophilus timoriensis* has thus been classified as Vulnerable (A1c, A2c) which means

> "Vulnerable, not Critically Endangered or Endangered, but facing a high risk of extinction in the world in the medium-term future, with population reduction in the form of either :
>
> (1) observed, estimated inferred or suspected reduction of 20% during the last 10 years or three generations, whichever is the longer by (c) a decline in area of occupancy, extent of occurrence and/or quality of habitat; or
>
> (2) a reduction of at least the rate specified in A1, projected or suspected to be met, based on (c) above." (Duncan *et al.* 1999)

An Action Plan for this species was prepared in 1999 (Duncan *et al*. 1999).

Sexual diversity.

Thirty four of the forty captured bats were males, of which twenty eight were mature, one was a young adult (*Vespadelus vulturnus*), and five were sub-adults (*Chalinolobus morio*). Of the six female bats captured one was in a pre-parous state (*C. morio*), and three were lactating (*C. morio*). One of the lactating females was a very mature bat with a small tear in one wing. Biological data for each bat is included in Attachment 6. The ten C*halinolobus morio* captured in one trap on the first night at the river red gum site adjacent to the river, included the five sub-adult males and the three lactating females. This capture result would suggest the trap was in close proximity to a roost site.

Body weight and forearm length

The biological data for *Chalinolobus morio* (Attachment 6) appears to show some sexual dimorphism as the females are larger than the males. The data for *Scotorepens greyii* also shows this trend.

Identification of species-combined ultrasound & capture technologies

Although only forty bats were captured during the 2003 Spring capture survey, three species were identified that were not differentiated by Anabat technologies. The frequency ranges used by *Nyctophilus* species overlap and the calls are short. Three *N. geoffroyi* were captured, as well as two *N. gouldi* and one *N. timoriensis*.

Species richness

The addition of harp trap capture increased the species identified by Anabat technologies from fourteen species and one genus to seventeen species. Fourteen of the seventeen species were confidently identified, one species was regarded as “probable”, and two as “possible”. Three other species identified in only the AE03 survey were assessed as “possible but unlikely”.

Table 6.1.d. Microbat species identified during four Anabat surveys 2003/04 (AE03 and SSA03/04) and one harp trap survey Spring 2003

Scientific name (Family and species)	**Common name**	**EA 2003 + SSA 2003/04 Surveys (a & b)**	**Harp Trap Spring 2003 Survey (c)**	**Combined**
Emballonuridae (Sheathtail bats)				
Saccolaimus flaviventris	yellow-bellied sheathtail bat	confident		confident
Vespertilionidae (Evening bats)				
Chalinolobus dwyeri	large-eared pied bat	possible/unlikely		possible/unlikely
Chalinolobus gouldii	Gould's wattled bat	confident	confident *	confident
Chalinolobus morio	chocolate wattled bat	confident	confident	confident
Chalinolobus picatus	little pied bat	confident		confident
Miniopterus schreibersii	large bentwing bat	possible/unlikely		possible/unlikely
Scotorepens balstoni	inland broadnosed bat	confident	confident	confident
Scotorepens greyii	little broadnosed bat	confident	confident	confident
Nyctophilus geoffroyi	lesser longeared bat	N. spp conf.	confident #	confident
Nyctophilus gouldi	Gould's longeared bat		confident #	confident
Nyctophilus timoriensis	greater longeared bat		confident #	confident
Vespadelus darlingtoni	large forest bat	probable		probable
Vespadelus regulus	southern forest bat	possible		possible
Vespadelus troughtoni	eastern cave bat	possible		possible
Vespadelus vulturnus	little forest bat	confident	confident	confident
Molossidae (Freetail bat)				
Mormopterus beccarii	Beccarii's freetail bat	possible/unlikely		possible/unlikely
Mormopterus sp. 2	eastern freetail bat	confident		confident
Mormopterus sp. 3	inland freetail bat	confident	confident	confident
Mormopterus sp. 4	southern freetail bat	confident		confident
Tadarida australis	white-striped freetail bat	confident		confident
Total number - species		**14 spp.+ 1 genus** (11 conf., 1 prob., 2 pos.) **+** (3 spp. pos/unlikely	**8 spp. +1?** (# 3 unident. by Anabat technologies)	**17 spp.** **(14 conf.,** **1 prob., 2 pos.);** **+(3 spp.pos/unlikely)**

KEY

EA 2003 + SSA 2003/04 Anabat surveys: 20 minutes recording at 102 sites over seven nights(EA03), and at 64 sites over eight nights each (SSA 2003/04) seasonal survey;

HT Harp trapping: 5 traps x 2 nights at 5 sites;

(a) Identified using: Herr 1995, Caddle & Lumsden 1997, de Oliveira 1998, Corben & O'Farrell 1999, Richards pers. com. 2000, and Reinhold *et al*. 2001;

(b) Identified using: Caddle & Lumsden 1997, de Oliveira 1998, Corben & O'Farrell 1999. 2000, and Reinhold *et al*. 2001, predominantly Pennay *et al*. 2004;

(c) Identified using: Churchill 1998 (parameters of known home range, forearm length, weight, description, photograph and release calls - verification by Pennay pers. comm. 2004).

Not identified to spp. using an Anabat recorder.

* Black morph.

Identification confidence and considerations

Anabat ultrasound technologies

The differences in species identification between the AE03 survey and the SSA03/04 surveys may be attributable to the utilisation of two different Keys for call identification. In the absence of any regional bat call references and the lack of both time and resources to establish such for the study area before the analysis of AE03 survey results, the Reinhold *et al.* 2001 "Key to the bat calls of south-east Queensland and north-east New South Wales" was utilised. The publication late in 2004 of the key "Bat calls of New South Wales" (Pennay *et al.* 2004) incorporating calls for the Western Slopes and Plains enabled a more accurate species identification for the SSA03/04 survey results. The Pennay *et al.* (2004) Key was also supplemented by release calls recorded for the species captured during spring 2003, the identifications verified by Pennay 2005 (pers. comm.).

For the six species classified as either "probable", "possible" or "possible but unlikely" neither the number of calls recorded nor the number of sites recording a presence were numerous. Three of these species utilise caves for breeding roost sites and as there are no known caves in the immediate proximity of the research area the roost selection outside the breeding season would need to be flexible in order for these species to be present in the research area. As many microbat species are opportunistic foragers, easy prey availability may be an influencing factor. A study in Sacremento Valley, USA, of Mexican free-tailed bats, a cave roosting species, reported a large colony inhabiting expansion joints in a freeway overpass located directly above a perennial stream surrounded by irrigated farmland (Freeman Long *et al.* 1998). The water supply infrastructure associated with cotton production does include large drains through banks and some cavity like structures.

"possible but unlikely"

Of the three species regarded as "possible but unlikely" and identified present only in the AE03 survey, *Chalinolobus dwyeri*, and *Miniopterus schreibersii* utilise caves as breeding roost sites and *Mormopterus beccarii* has a distribution range exclusively north of the Queensland border. Both cave roosting species have been recorded at Mt. Kaputar National Park approximately 50 km. away from the research area.

The calls of ***Chalinolobus dwyeri*** can easily be distinguished from other species by the combination of the low frequencies and distinct pattern of alternation present in search phase calls (Pennay *et al.* 2004). The study area is within the *Chalinolobus dwyeri* distribution rangeand although this species roosts in caves the twilight area not far from a cave entrance is the most common roost location Churchill (1998) cited reports of single males over-wintering in mine shafts, and one juvenile male over-wintering in an abandoned Fairy Martin (*Hirundo ariel*) nest.

The distribution for *Chalinolobus dwyeri* is poorly known and in 1999 (Duncan *et al.*1999) it appeared to be uncommon in New South Wales, and rare within its range in Queensland. Its habitat is poorly understood; it has been recorded from a range of vegetation types including dry schlerophyl and *Callitris* dominated forests. It has been classified Vulnerable (A1a, C2a), meaning not Critically Endangered or Endangered, but facing a high risk of extinction in the world in the medium-term future; the estimated population from direct observations is less than 10,000; observed, projected or inferred numbers of mature individuals are in continuing decline and the population structure is severely fragmented with no population estimated to contain more than 1,000 (Duncan *et al*. 1999).

Although the study area is outside of distribution range for the third species, ***Mormopterus beccarii*** are commonly caught along watercourses lined with river red gums in arid areas (Churchill 1998). Pennay *et al.* (2004) reported that calls have occasionally been recorded from free flying bats around Gunnedah, Narrabri and Moree matching characteristics of *M. beccarii* calls from Queensland but the identity of the species producing the calls has not been confirmed. No reference calls for *M. beccarii* are available from New South Wales, and their calls may be confused with *Saccolaimus flaviventris,* however *S. flaviventris* rarely call above 22 kHz (Pennay *et al*. 2004).

Vespadelus species

Four *Vespadelus* spp. were recorded as present in the Anabat landscape surveys - *V. darlingtoni* (probable), *V. regulus* (possible), *V. troughtoni* (possible) and *V. vulturnus* (confident). *V. regulus* and *V. troughtoni* were identified in the SSA03/04 surveys, but not during the AE03 survey.

Although the study area fits within the distribution range for both *V. regulus* and *V. troughtoni* (Pennay *et al.* 2004), the species with similar distribution range to the research area, *V. troughtoni*, is a cave roosting species.

Extensive geographic variation occurs in echolocation calls of *Vespadelus* spp. (Law *et al.* 2002). Although the calls of ***V. vulturnus*** vary regionally several very clear long-sequence release calls (47-49 kHz) recorded during the Spring 2003 Harp trap survey enabled accurate identification of calls for this species.

On the other hand the calls of ***V. troughtoni*** are consistent throughout its range (Law *et al.* 2002) and regional reference calls were available (Pennay *et al.* 2004). Although the frequency range used by *V. troughtoni* overlaps the frequency range used by *Chalinolobus morio*, the calls of *V. troughtoni* (48-55 kHz) are easily distinguished by the presence of an upsweeping tail (Pennay *et al.* 2004). While selecting caves for roost sites, *V. troughtoni* has a preference for well-lit areas near entrances and have also been found to roost in boulder piles, mine tunnels and occasionally buildings (Churchill 1998). They are reported to inhabit tropical mixed woodland and wet sclerophyll forest on the coast and the dividing range, as well as the drier forest of the western slopes and inland areas.

Whilst distribution ranges for both ***V. regulus*** and ***V. darlingtoni*** extend across the study area, the unavailability of regional reference calls as well as extensive geographic call variation for both species limited clear identification of calls for these species. The ultrasound echolocation frequency ranges used for these species were 41-44 kHz for *V. darlingtoni*, and 45-46 kHz for *V. regulus* (Pennay *et al.* 2004, and Law *et al*. 2002).

Harp trap capture technologies

A bat captured at the Cypress pine site was initially identified as either a *Chalinolobus dwyeri* or *Chalinolobus picatus* because of the very black colour of its coat. The study area is within the known distribution range for both species, however a forearm length of 43.9 mm and weight of 11.6g and the absence of white stripes ruled out both these species. The release call identified this impressive bat as a black *Chalinolobus gouldii*. The identification was verified by M. Pennay (pers. comm. 2005), after the examination of photographic documentation and release calls.

Combining both ultrasound and capture technologies - summary

Capture thus enabled the identification of the *Nyctophilus* genus into three different species (*N. geoffroyi*, *N. gouldi*, *N. timoriensis*). Biological and release call identification associated with trap capture enabled verification of six (*Chalinolobus gouldii*, *Chalinolobus morio*, *Scotorepens balstoni*, *Scotorepens greyii*, *Vespadelus vulturnus*, *Mormopterus* sp. 3) of the eleven species confidently identified using Anabat technologies.

Although two fast high flying species, *Saccolaimus flaviventris* and *Tadarida australis*, are not usually captured in harp traps, their ultrasound frequencies are not likely to be confused with any other species. The remaining three species that were confidently identified with Anabat technologies (*Chalinolobus picatus*, and *Mormopterus* sp. 2 and 4) remained unconfirmed by capture.

The identification of three species as either "probable" (*Vespadelus darlingtoni*) or "possible" (*V. regulus* and *V. troughtoni*) during the SSA 03/04 using Pennay *et al*. 2004 remained the same. Because *Chalinolobus dwyeri*, *Miniopterus schreibersii* and *Mormopterus beccarii* were recorded only during the AE03 survey and their identification utilised Reinhold *et al.* (2001), when these species were neither recorded during SSA03/04 surveys nor captured, the identifications were downgraded from "possible" to "possible but unlikely".

6.1.2 SEASONAL DIVERSITY

Seasonal variation - species richness

Seasonal variation occurred in species richness as set out below:

- autumn 2003 - twelve species and two genera;
- spring 2003 - sixteen species (includes three species identified by spring harp trapping but not identified to spp. level in summer and autumn);
- summer 2004 - eleven species and one genus;
- autumn 2004 - twelve species and one genus.

The confident identification of species varied seasonally between eight and fourteen. There was also a seasonal variation in species identified as "probable", "possible" and "possible but unlikely" (Table 6.1e).

Table 6.1.e. Confidence rating of species identification

Season 2003/04 and Survey	Species (confident)	Species (probable)	Species (possible)	Species (pos/unlikely)	Genera	Total
Autumn '03 (EA03)	8	1		3	2	12spp. 2 gen
Spring '03 (SSA03/04+HT)	14		2			16 spp.
Summer '04 (SSA03/04)	10	1			1	11 spp. 1 gen
Autumn '04 (SSA03/04)	11	1	1		1	12 spp. 1 gen

Seasonal presence - individual species

Seasonal variation occurred in the presence of individual species (Table 6.1f).

Presence across all four seasons (autumn and spring 2003, summer and autumn 2004) was recorded for the only Emballonurid species (*Saccolaimus flaviventris*), and six of the fourteen Vespertillionid species (*Chalinolobus gouldii*, *Chalinolobus morio*, *Chalinolobus picatus*, *Scotorepens balstoni*, *Scotorepens greyii* and *Vespadelus vulturnus*). Calls of *Nyctophilus* genus were also recorded across all seasons but were identified to species level only in spring based on capture data.

The seasonal variation of two Vespertillionid species (*Chalinolobus dwyeri* and *Miniopterus schreibersii*) and four of the five Mollossid species (*Mormopterus beccari*, *Mormopterus* spp. 2, 3 and 4) showed marked seasonal variation between autumn 2003 (AE03) and the subsequent three seasons (SSA03/04). The first two species were recorded only in the AE03 survey, the last three species were not identified in autumn 2003 but recorded and identified during the subsequent three seasons.

The other Molossid species (*Tadarida australis*) was not recorded in summer 2004.

Table 6.1.f . Microbat species – seasonal presence

Botanical name (Family and species)	Autumn 2003 **AS**	**Spring 2003 AS+HT**	**Summer 2004 AS**	**Autumn 2004 AS**	**Seasonal Presence** (shaded = all seasons present)
Emballonuridae (Sheathtail bats)					
Saccolaimus flaviventris	■	■	■	■	▨
Vespertilionidae (Evening bats)					
Chalinolobus dwyeri (vulnerable)	pos/unlikely	**nr**	**nr**	**nr**	autumn ’03 only
Chalinolobus gouldii	■	■	■	■	▨
Chalinolobus morio	■	■	■	■	▨
Chalinolobus picatus	■	■	■	■	▨
Miniopterus schreibersii	pos/unlikely	**nr**	**nr**	**nr**	autumn ’03 only
Scotorepens balstoni	■	■	■	■	▨
Scotorepens greyii	■	■	■	■	▨
Nyctophilus geoffroyi	*N.* genus	■	*N.* genus	*N.* genus	genus all seasons; all species identified in spring;
Nyctophilus gouldi		■			
***Nyctophilus timoriensis* (vulnerable)**		■			
Vespadelus darlingtoni	probable	**nr**	probable	probable	summer & autumn; not recorded spring;
Vespadelus regulus	**nr**	possible	**nr**	**nr**	spring only; absent summer & autumn.
Vespadelus troughtani	**nr**	possible	**nr**	possible	spring & autumn; not recorded summer.
Vespadelus vulturnus	■	■	■	■	▨
Mollossidae (Freetail bat)					
Mormopterus beccarii	pos/unlikely	**nr**	**nr**	**nr**	autumn ’03 only
Mormopterus sp. 2		■	■	■	▨
Mormopterus sp. 3 (small penis)	Spp. ?	■	■	■	▨
Mormopterus sp. 4 (large penis)	Spp. ?	■	■	■	▨
Tadarida australis	■	■	**nr**	■	not recorded summer
Total number - species	**12 spp.+ 2 genera** (8 conf., 1 prob., 3 pos/ unlikely	**16 spp.** (14 conf., 2 pos.)	**11 spp.+ 1 genus** (10 conf., 1 prob.)	**13 spp. + 1 genus** (11 conf., 1prob.,1 pos)	

KEY
AS Anabat survey: 20 minutes recording at 102 (exploratory), and 64 (seasonal) sites over 7 & eight nights
HT Harp trap survey, 5 traps at 5 sites for two nights each.
nr not recorded

The three remaining Vespertillionid species belonging to the *Vespadelus* genus showed a seasonal variability with some relationships to the separation of results between autumn 2003 (AE03) and the other three seasons (SSA03/04), however they also showed additional seasonal variability. *Vespadelus darlingtoni* was absent in spring 2003, *V. regulus* present only in spring 2003, and *Vespadelus toughtoni* present only in spring 2003 and autumn 2004.

Factors determining variability in species richness

Seasonal variability was greatest between the AE03 and SSA03/04 surveys. The different methods of identification would appear to account for the some of the seasonal variability in species richness (*Chalinolobus dwyeri*, *Miniopterus schreibersii* and all the *Mormopterus* species) between autumn 2003 and the three subsequent seasons.

A discrepancy occurred that questioned this apparent relationship, however. An unmistakably very high call abundance and very high presence was recorded in autumn 2003 for *Tadarida australis* that was not replicated in autumn 2004. It was also not explained by any change in Anabat recording sensitivity which remained constant throughout all surveys. In Western Australia *T. australis* has a winter range expansion northward of up to 200 km and a summer contraction southward that is correlated with an interaction of temperature and humidity. It is suggested that a limiting factor for this correlation is possibly related to flight muscle heat (Bullen and McKenzie, 2005). Thus, climatic factors could be an influence on the behaviour of other species.

Seasonal call variation

Because they could not be identified, a group of very different microbat calls between 27kHz and 33 kHz was not included in any of the above results. The calls, numbering 22 in spring, 2 in summer and 162 in autumn, displayed an initial flat minimum frequency shape with or without a downward tail, pulses descending, sometimes with some alternation, in groups of 5 or 7 pulses. The groups were variously repeated. The calls fitted within the ultrasound frequency ranges utilised by both *Chalinolobus gouldii* and *Mormopterus* sp. 2. Their seasonal distribution could possibly be ascribed to seasonal variations for either species. Recent research suggests that by increasing band-width or ultrasound frequency range, primarily to the first pulse, some species greatly improve prey detection ability, specifically close to vegetation (Siemers and Schnitzler 2004). As autumn is accompanied by reductions in prey populations, call variation may be greatly advantageous.

Regional variation occurs in calls of many *Vespadelus* species including both *Vespadelus regulus* and *V. darlingtoni*. The closeness of the frequency ranges utilised by these species, the absence of *V. darlingtoni* in spring only, and the presence of *V. regulus* only in spring, suggests that seasonal variation may also occur in calls for these species and possibly others.

A landscape composed of a matrix of seasonal crops providing seasonally varying populations of prey could consequentially be influencing seasonal distribution of either specialist or generalist microbat species.

6.1.3 SPECIES RICHNESS

Cotton production versus natural areas of the region.

This section compares the species diversity of the cotton landscape of the current study with Mt. Kaputar National Park and Brigalow Park Nature Reserve. The results for both Parks are based on limited survey results.

Mt. Kaputar National Park, only 50 km from the study area varies in altitude and climatic conditions, vegetation composition, age and density and contains many rocky escarpments and outcrops. It would therefore be expected to provide foraging, tree hollow and cave roosting habitat for an extensive diversity of microbat species. Brigalow Park Nature Reserve, on the other hand, would be expected to provide fewer opportunities for microbat species than Mt. Kaputar National Park, and cotton production landscapes even less. The twelve species listed for Mt. Kaputar National Park include five cave roosting species of which two were not recorded in the study area. Although two other species were recorded, their identification is regarded as “possible but unlikely”. The eight species listed for Brigalow Park Nature Reserve were all recorded in the study area. Conversely the intensive agricultural cotton production landscape of the research area provided habitat for between fourteen and seventeen species, with a possibility of three more (Table 6.1g) - a surprisingly high species richness. These included three species not recorded at either Mt. Kaputar or Brigalow Park Nature Reserve (*Chalinolobus picatus*, *Nyctophilus timoriensis* and *Mormopterus* sp. 2.) and four other species not recorded at Mt. Kaputar, *Vespadalus regulus* (possible) *V. troughtoni* (possible), *Mormopterus* sp. 4 and *Mormopterus* sp. 3.

Table 6.1.g Microbat species previously identified witin the region of the study
(Identifications made by: P. McInnes, National Parks & Wildlife Service, Narrabri; Glen Hoye, Fly By Night Bat Surveys Pty. Ltd. for M. Heinze, National Parks & Wildlife Service, Narrabri; G. Richards; all personal communication and unpublished

Microbat family, genus and species		**National Park & Nature Reserve**		**Cotton landscape Previous research**			**Cotton landscape**
Botanical name	Common name	Mt. Kaputar National Park (McInnes 2001)	Brigalow Park Nature Reserve (Heinze 2002)	Woodland adjacent water (Richards 2000)	Cotton adj. remnant vegetation (Richards 2000)	Cotton Isolated from veg. (MacKinnon 2001)	**Current Research 2003/04**
Emballonuridae (Sheathtail bats)							
Saccolaimus flaviventris	yellow-bellied sheathtail	■			■		■
Rhinolophidae (Horseshoe bats)							
Rhinolophus megaphyllus	eastern horseshoe	■					
Vespertilionidae (Evening bats)							
Chalinolobus dwyeri *****	large-eared pied	■					pos/unlikely
Chalinolobus gouldii	Gould's wattled	■	possible	■	■		■
Chalinolobus morio	chocolate wattled	■	probable	■	■		■
Chalinolobus picatus	little pied						■
Miniopterus schreibersii	large bentwing						pos/unlikely
Miniopterus schreibersii oceanensis	eastern bentwing	■					
Miniopterus australis	little bentwing	■					
Scotorepens balstoni	inland broadnosed	■	probable	■	■	■	■
Scotorepens greyii	little broadnosed	■	possible	■		■	■
Nyctophilus geoffroyi	lesser longeared	■	■				■
Nyctophilus gouldi	Gould's longeared	■					■
Nyctophilus timoriensis *	greater longeared						■
Vespadelus darlingtoni	large forest	■					probable
Vespadelus regulus	southern forest						possible
Vespadelus troughtani	eastern cave						possible
Vespadelus vulturnus	little forest	■	probable	■			■
Mollossidae (Freetail bat)							
Mormoptorus beccarii	Beccarii's freetail						pos/unlikely
Mormoptorus sp. 2	eastern freetail						■
Mormopterus sp. 4	southern freetail		■	■	■		■
Mormopterus sp. 3	inland freetail		■	■	■	■	■
Tadarida australis	white-stripedfreetail	■		■	■		■
Total number – species		12	8	8	7	3	17 + 3 pos/unlikely

* Vulnerable

Species richness and best sampling time

The high species richness recorded in the research area was the outcome of extensive nocturnal and seasonal, as well as spatial sampling. The 56km² cotton production landscape of the study area was sampled for microbat activity four times, firstly at 102 sites over 7 nights in autumn, and subsequently three times, in spring, summer and autumn at 64 sites over eight nights. It was supplemented with capture in spring. Much microbat research combines ultrasound and capture technologies, but sampling is usually limited to spatial comparisons. These are often conducted in either spring or summer, but rarely in autumn. Even accounting for identification anomalies, species richness in the research area was unexpectedly at it lowest in summer (Table 6.1h). Sampling conducted only in summer would have excluded *Tadarida australis*, and missed the season of the greatest presence for this species, in autumn. Sampling in spring or summer would also have excluded the unidentified group of calls or the seasonal variation in either *Chalinolobus gouldii* or *Mormopterus* sp. 2 calls and missed the presence of a species present mainly in autumn,. These results, illustrated in the Species Richness Index below, highlight the importance of temporal seasonal sampling, and the inclusion of autumn sampling. Because *Nyctophilus* species were identified only in spring to species level via trapping, these species have been removed from the Species Richness Index (Table 6.1h)

Table 6.1.h. Species Richness Index, Seasonal comparison of species richness excluding *Nyctophilus* genus

	Autumn 2003	**Spring 2003**	**Summer 2004**	**Autumn 2004**
Number of species	12	**13**	11	**13**

The apparent seasonal differentiation in species richness has been examined in this chapter. Later chapters will examine seasonal variation in activity and distribution.

6.1.4 CONCLUSIONS

The above results have significantly expanded the current list of known species for the study area. The results in this chapter however illustrate the difficulty of seasonal as well as regional call identification. The results also illustrate the necessity for surveys to be conducted across a number of seasons.

The apparent species richness results in spring during early cotton production and in autumn post-cotton production, suggest that the microbat fauna is being supported by insect food sources during times of both increased insect abundance associated with cotton production and insect availability outside times of cotton production.

The species richness results also suggest the availability of a wide range of roosting sites catering for species roost selection differences as well as seasonal variability of requirements.

Table 6.A. Biological data – Harp Trap Survey November 2003 (ordered in sex, size and weight)

Species – (ID verification M. Pennay from release calls & photographs)	**Forearm length** mm.	**Weight** g.	**Sex**	**Age** Adult, Sub Adult	**Reprod. Condit.** (Pregnant/ Lactating, Sexual Maturity)
Vespertilionidae (Evening)					
*Chalinolobus gouldii (*black morph)	43.9	11.6	M	A older	
Chalinolobus morio	38.9	9	F	A	lactating
Chalinolobus morio	38.8	9	F	A+ tear in wing	lactating
Chalinolobus morio	38.2	8	F	A	neither preg. nor lac.
Chalinolobus morio	38.2	7.8	F	A preg?	pre prod
Chalinolobus morio	36.8	8	F	A	lactating
Chalinolobus morio	38.2	7.6	M	A	
Chalinolobus morio	38.1	8	M	SA	
Chalinolobus morio	38.1	7.5	M	SA	
Chalinolobus morio	37.8	7.8	M	A	
Chalinolobus morio	37.7	7.5	M	A	
Chalinolobus morio	37.6	8.5	M	SA	
Chalinolobus morio	37.3	7.5	M	A	small male with testies
Chalinolobus morio	37	7.5	M	SA	
Chalinolobus morio	36.4	7	M	SA	
Nyctophilus geoffroyi	35	6	M	non juv	
Nyctophilus geoffroyii	33.9	5.5	M	A	
Nyctophilus geoffroyii	33.6	6	M	A	
Nyctophilus gouldi	39.5	7.5	M	A	
Nyctophilus gouldi	39.3	7.2	M	A	
Nyctophilus timoriensis Vulnerable	44.2	14.8	M	A+	
Scotorepens balstoni	35.5	10.2	M	A	
Scotorepens balstoni	32.5	7.5	M	A	
Scotorepens greyii	31.5	8	F	A	neither preg. nor lact.
Scotorepens greyii	31.4	6.5	M	A	
Scotorepens greyii	30.1	6.5	M	A	
Scotorepens greyii	30.6	6	M	A	
Scotorepens greyii	30	6.1	M	A	
Scotorepens spp.	30.0	6.8	M	A	
Vespadelus vulturnus	28.6	3.7	M	A	
Vespadelus vulturnus	27.3	3.75	M	A	
Vespadelus vulturnus	27.3	3.8	M	A	
Vespadelus vulturnus	27.2	3.5	M	A	
Vespadelus vulturnus	27	3.6	M	A	
Vespadelus vulturnus	26.8	3.8	M	Y/A	
Vespadelus vulturnus	26.1	3.5	M	A	
Vespadelus vulturnus	26	3.5	M	A	
Vespadelus vulturnus	25.6	3.5	M	A	
Mollossidae (Freetail)					
Mormopterus sp. 3	34.2	8.2	M		penis 4; tail 21.4
Mormopterus sp. 3	30.2	7.5	M	A	tail 18

CHAPTER 6.2 MICROBAT PATTERNS OF ACTIVITY

Contents

INTRODUCTION For microbats, energy expenditure on flight must be met by energy income from prey consumption. Patterns of activity should therefore be related to efficiency of predation. If there is a microbat presence across a cotton production landscape how does the presence manifest? To commence the establishment of possible linkages between microbats, cotton and native vegetation this chapter examines both seasonal and nocturnal patterns of activity for individual species and the assemblage of microbats. Later chapters will examine the interrelationships between microbat activity, feeding activity, insects and climatic conditions.

6.2.1 SEASONAL TOTAL CALL ABUNDANCE

For each of the three SSA03/04 surveys, microbat activity was recorded for a total of 21 hours 20 minutes. From the 3,843 (spring), 5,450 (summer) and 3,257 (autumn) ultrasound files recorded, the microbat total call abundance was respectively 605, 610 and 512. Total call abundance for microbat calls identified to species level was in spring 576, in summer 544 and in autumn 512. Microbat calls not identified to species level numbered 29 in spring, 66 in summer and 52 in autumn.

6.2.2 SEASONAL AND NOCTURNAL PATTERNS OF TOTAL CALL ABUNDANCE

Examination of the microbat call data showed extensive seasonal as well as nocturnal variation in the distribution of call abundance (Fig. 6.2a). Time-of-night sampling times are arranged as set out in Table 4.5b above.

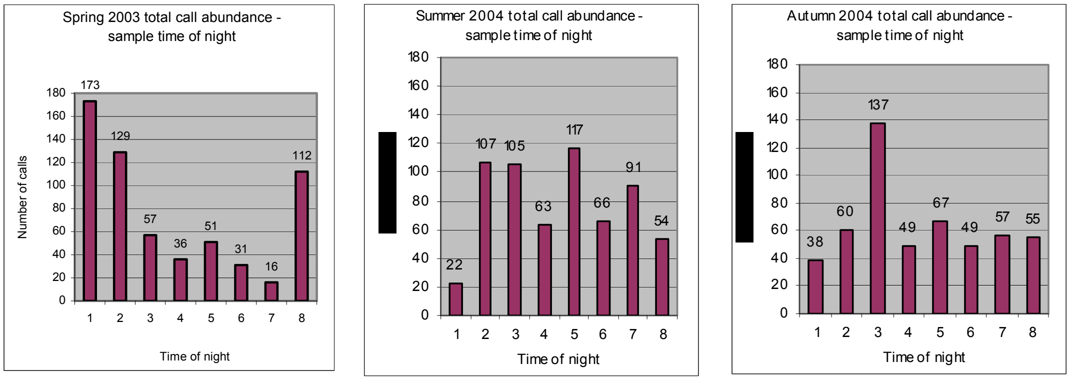


Fig. 6.2.a. Spring, summer and autumn comparisons of total call abundance for each sampling time commencing at civil twilight (spring and summer) and sunset (autumn) concluding approximately 12.30 am. (Summer data for 7.5 nights)

Spring results showed a pattern of sizeable peaks of activity at the commencement (T1 and T2) and conclusion (T8) of the nightly sampling session, with a small activity increase during T5. Reductions in activity occurred in T7 as well as T4 and T6. Summer results, after very limited activity during T1, showed a generally oscillating pattern, with greatest activity occurring in T2, T3, T5 and T7.   Apart from low call activity in T1, reduced levels of activity for summer were recorded in T4, T6 and around midnight during T8.   On the other hand the autumn results showed a singular peak pattern of activity in T3, sitting between a gradual activity rise from T1 to T2, and similar but oscillating results for times T4 to T8. The times of some reduction in activity in autumn were T1, T4 and T6.

The seasonal and nocturnal patterns in total call abundance shown in Fig. 6.2a. will be used as a template for comparisons of other results. This template will be referred to as “the TCA.6.2 activity patterns”.

Maximum, Mean and Quartiles

A separation of total call abundance data into minimum, maximum, mean and upper and lower quartile statistical parameters, shown in Fig. 6.2b, identified differing sets of influences that are examined below.

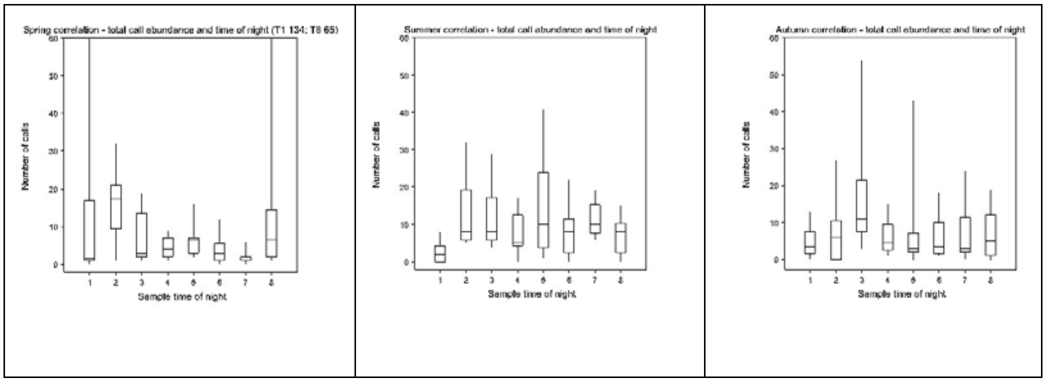


Fig 6.2.b. Spring, summer and autumn comparisons of total call abundance and sample time of night.
Data for each sample time of night includes maximum, minimum and median call abundance, error bars indicate 25%-75% percentiles;
n = 8 (20 minute sample replicated 8 times = 160 minutes) Note Spring maximums T1=134; T8=65

Mean of total call abundance

The results for Mean call abundance (Table 6.2a) generally reflected the seasonal patterns of activity described in TCA.6.2 with peaks for spring in T1, T2 and T8, summer oscillations and peaks in T2, T3, T5 and T7, and a singular T3 peak in autumn.

Table 6.2.a. Seasonal comparison of the mean number of calls for each sampling time (160 mins of sampling)

SSA03/04	T1	T2	T3	T4	T5	T6	T7	T8
Spring	**21.6**	**16.1**	7.1	4.5	6.4	3.9	2.0	**14.0**
Summer	2.4	**13.1**	**12.3**	7.6	**14.7**	8.3	**11.4**	6.9
Autumn	4.8	7.5	**17.1**	6.1	8.4	6.1	7.1	6.9

Maximum and Median of total call abundance

However the maximum call abundance data identified a strong influence from individual sites (Fig. 6.2b and Table 6.2b), and combined with median total call abundance the greatest influence from single sites was shown to be during three sample times in spring (T1, T8, T2), four in summer (T5, T3, T2, T6) and four in autumn (T5, T3, T2, T7). On the other hand for five of these sample times the results from single site did not result in TCA.6.2 peaks in activity - spring T3, summer T6, and three of the four autumn times T2, T5 and T7.

The identification of the single sites, their landscape categories, and the number of calls recorded are set out in Table 6.2b. Although sampled at different sampling times high maximum call abundance was recorded consistantly at several sites i.e. at site Cd high call abundance was recorded in spring during T2 and summer and autumn during T6; at Ca in spring and summer during T1 and T5 respectively; at Em during T3 in both spring and summer; at Ce in spring and autumn during T3 and T8 respectively ; and at Go in summer and autumn during T1 and T2 respectively.

The influence of individual sites is best demonstrated by the results for autumn T5, a sample time that did not show a general peak in activity (TCA.6.2). The 43 calls recorded at site Ac during autumn T5 contributed 64% of the total 67 calls recorded for T5 over eight nights. It is also noteworthy two of the individual sites influencing results listed in Table 6.2.b, Em and Hd, are irrigated cropping sites, and only the summer Em (T3) results contributed to TCA.6.2 assemblage peaks in activity.

Table 6.2.b. Seasonal comparison of sample sites with maximum total call abundance

Sample time	**Spring** **Sample site identification;** **(number of calls);** **landscape category**	**Summer** **Sample site identification;** **(number of calls);** **landscape category**	**Autumn** **Sample site identification;** **(number of calls);** **landscape category**
T1	**• Ca (134) rgf**	**Go (8) dc/rr**	**Hl (13) pb**
T2	**• Cd (32) mix**	**• Hg (32) pb**	**Go (27) dc/rr**
T3	**Em (19) ic#; Ce(19) rgow**	**• Em (29) ic #**	**• Ff (54) rgow**
T4	**Cl (9) pb**	**Hd (17) ic #**	**Ad (15) rgow**
T5	**Co (16) mix**	**• Ca (41) rgf**	**Ac (43) rgow**
T6	**Da (12) gb**	**Cd (22) mix**	**Cd (18) mix**
T7	**Eb (6) rgow**	**• Ab (19) rgow**	**Ai (24) rgow**
T8	**• Ea (65) pb**	**Ac (15) rgow**	**Ce (19) rgow**

KEY

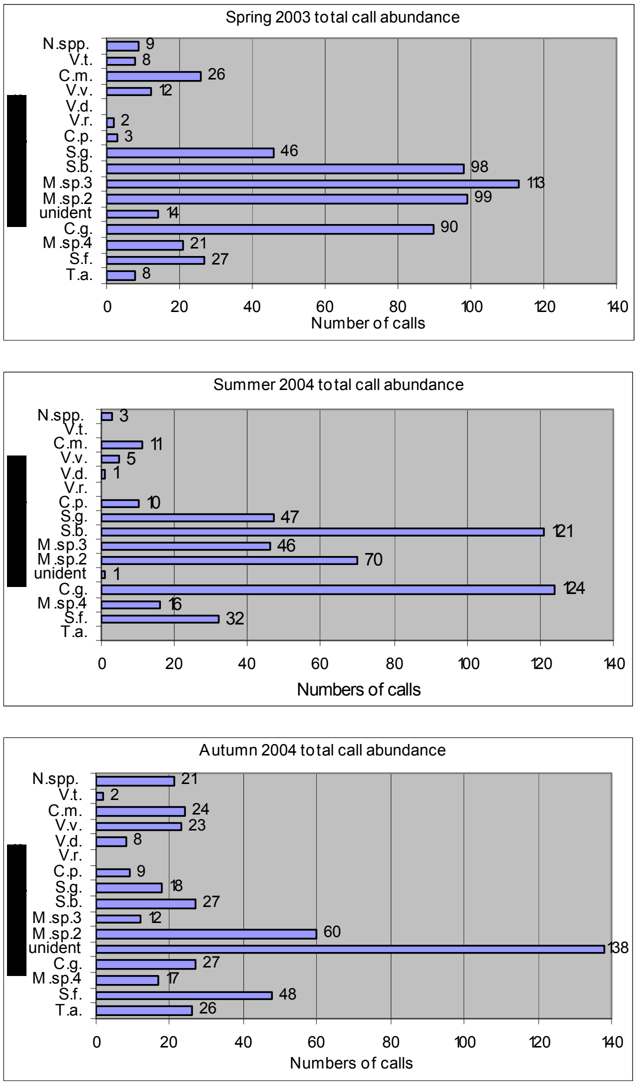
•	peak activity sample times shown in TCA.Fig.6.2a.;
Landscape category:	rgf (river gum forest); rgow (river gum open woodland); pb (poplar box); gb (grey box); mix (mixed spp. remnant); ic (irrigated cropping); dc (dryland cropping); rr (roadside remnant)
#	irrigated cropping sites
colours	**sample site repetition**

Further influence of individual site results can be seen in the combination of median and upper and lower quartiles. The positioning of this data did not necessarily reflect the peaks in activity described in TCA.6.2. An example can be seen by the comparison of spring sample times T1 with T2 results in Fig.6.2b and TCA.6.2. Although the highest max call abundance was recorded in T1 (173), the positioning of the quartiles and median indicated an uneven spread of the data. One hundred and thirty four (77%) of those calls were recorded at one site. Although call abundance for T2 was lower than for T1 the distribution of the quartiles and median indicated a more even spread of the data ie. 32 calls (24%) were recorded at one site, the remaining 97 calls were spread more evenly across the eight-night sample.

These results show that at some sampling sites consistently high levels of activity were recorded at differing sampling times and/or across different seasons. The results from these sites in most instances were consistant with the overall seasonal patterns of activity but some were not. The landscape categories represented by these individual sites across the three seasons were rgf (1), rgow (7), mix (2), pb (4), grey box (1), dc/rr (1) and ic (2)

6.2.3 SPECIES PATTERNS OF SEASONAL TOTAL CALL ABUNDANCE

Considerable variation in activity levels was recorded between seasons and species (Fig. 6.2c). The microbat species (Fig. 6.2c) are arranged according to the ultrasound echolocation frequency ranges used – lowest 10-13 kHz (*Tadarida australis*), to highest 49-70 kHz (*Nyctophilus* spp.).



KEY

High kHz ultrasound

↑

Microbat species

N. spp.	*Nyctophilus*. spp.
V.t.	*Vespadelus troughtoni*
C.m.	*Chalinolobus morio*
V.v.	*Vespadelus vulturnus*
V.d.	*Vespadelus darlingtoni*
V.r.	*Vespadelus regulus*
C.p.	*Chalinolobus picatus*
S.g.	*Scotorepens greyii*
S.b.	*Scotorepens balstoni*
M.sp.3	*Mormopterus* sp. 3
M.sp.2	*Mormopterus* sp. 2
unident	unidentified calls
C.g.	*Chalinolobus gouldii*
M.sp.*4*	*Mormopterus* sp. 4
S.f.	*Saccolaimus flaviventris*
T.a.	*Tadarida australis*

↓

Low kHz ultrasound

Fig. 6.2.c. Seasonal comparisons of total call abundance for individual microbat species - SSA03/04 surveys.

The highest call abundance in spring was recorded by four species, *Mormopterus* sp. 3 (113 calls), *Mormopterus* sp. 2 (99), *Scotorepen balstoni* (98) and *Chalinolobus gouldii* (90) and accounted for 69% of the spring total abundance. In summer two of the same species, *C. gouldii* (124) and *S. balstoni* (121), recorded 50% of all summer calls. Although *Mormopterus* sp. 2 (70), and two other species, *S. greyii* (47) and *Saccolaimus flaviventris* (32) recorded another 30% of summer calls, the results for these species were between 43% and 74% lower than those for *C. gouldii* and *S. balstoni*. In autumn the unidentified group of 138 calls recorded the highest call abundance and accounted for 30% of all autumn calls. While *Mormopterus* sp. 2 (60 calls) and *S. flaviventris* (48) accounted for another 23% of autumn calls, their total call abundance was respectively 57% and 66% lower than for the unidentified group of calls.

6.2.4 INDIVIDUAL SPECIES SEASONAL & NOCTURNAL PATTERNS OF ACTIVITY (Total call abundance)

For individual species the patterns of total call abundance showed both nocturnal and seasonal variation. Broad variation occurred in the general level of call abundance.

Seasonal activity

Although differing in abundance, the patterns of activity for both *Mormopterus* sp. 4 and *Mormopterus* sp. 2 showed seasonal evenness with a slight spring predominance. However the patterns of call abundance for many species showed considerable variation between seasons (Table 6.2c). Set out in Attachment 6.2 are the seasonal and nocturnal activity patterns for individual species, grouped to show seasons of highest activity.

Table 6.2.c. Species seasonal distribution of total call abundance

	Even /sp.		**Spring predom.**			**Sp/ Su**	**Sp/ Au**	**Summer predom.**			**Autumn predominance**					
Spp.	M.4	M.2	M.3	V.t	V.r	S.g	C.m	S.b	C.g	C.p	S.f	V.v	N.sp	unid	T.a	V.d
Spring	**21**	**99**	**113**	**8**	**2**	**46**	**26**	**98**	**90**	3	27	**12**	**9**	**14**	**6**	a
Summer	16	**70**	**46**	nr	nr	**47**	**11**	**121**	**124**	**10**	**32**	5	3	1	nr	**1**
Autumn	**17**	60	12	**2**	nr	**18**	**24**	27	27	**9**	**48**	**23**	**21**	**138**	**26**	**8**

KEY

(red)	highest call abundance	(blank)	lowest call abundance	(nr)	not recorded
T.a.	*Tadarida australis*	**M.3**	*Mormopterus sp. 3*	**V.v.**	*Vespadelus vulturnus*
S.a.	*Saccolaimus flaviventris*	**S.b.**	*Scotorepens balstoni*	**C.m.**	*Chalinolobus morio*
M.4	*Mormopterus* sp. 4	**S.g.**	*Scotorepens greyii*	**V.t.**	*Vespadelus troughtoni*
C.g.	*Chalinolobus gouldii*	**C.p.**	*Chalinolobus picatus*	**N.spp**	Nyctophilus spp.
Unid.	Unidentified group of calls	**V.r.**	*Vespadelus regulus*		
M.2	*Mormopterus* sp. 2	**V.d.**	*Vespadelus darlingtoni*		

Spring was the season of highest call abundance for *Mormopterus* sp. 3, *Vespadalus troughtoni* and *Vespadelus regulus*. *V. troughtoni* was not recorded in summer; *V. regulus* was not recorded in summer and autumn. Whilst spring and summer were the seasons of highest recorded activity for *S. greyii*, spring and autumn were the seasons of highest activity for *C. morio*. Summer was the season of highest call activity for *S. balstoni*, *C. gouldii*, and with greatly reduced abundance, *Chalinolobus picatus*.

Even though in general autumn levels of call activity were reduced, six species showed varying intensities of predispositions to autumn call activity. These species were *S.*

flaviventris, *Vepadelus vulturnus*, *Nyctophilus* spp., the “unidentified group of calls”, *Tadarida australis*, and *Vespadelus darlingtoni*. These results were influenced by spring or summer absence for some species: *T. australis* absent in summer, *V. darlingtoni* absent in spring, and only one call each recorded in summer for the “unidentified group of calls” and *V. darlingtoni*.

The season of least call activity was spring for *C. picatus,* with no calls recorded for *V. darlingtoni*. Summer was the season of least activity for *Chalinolobus morio*, *V. vulturnus*, *Nyctopphilus* spp., the “unidentified group of calls”, and no calls recorded for *T. australis*, *V. troughtoni* and *V. regulus*. Autumn was the season of least activity for *Mormopterus* sp. 2, *Mormopterus* sp. 3, *Scotorepens greyii*, *S. balstoni*, *C. gouldii*, with no calls recorded for *V. regulus*.

Replication of seasonal patterns of total call abundance

The patterns of activity in call abundance for some species either fully or partially replicated the TCA.6.2 seasonal and nocturnal activity patterns, but the activity patterns of other species did not (Fig 6.2d).

The spring TCA.6.2 activity patterns were replicated by only two species, *C. goudii* and *S. balstoni*, however portions of the pattern were repeated by *Mormopterus* sp. 2, *Mormopterus* sp. 3, *S. greyii*, *C.* mori, and where present *V. troughtoni*. Summer TCA.6.2 activity patterns were replicated by six species, *S. flaviventris*, *C. gouldii*, *Mormopterus* sp. 3, *S. balstoni*, *C. picatus*, and where present *V. darlingtoni*. The activity patterns of seven species in autumn replicated to varying degrees, the patterns shown in TCA.6.2. These species were, *S. flaviventris*, *Mormopterus* sp. 2, *Mormopterus* sp. 4, *S. greyii*, *C. picatus*, where present *V. darlingtoni, Mormopterus* sp. 3 in a reduced fashion, and partially by *V. vulturnus* and *C. morio*.

The TCA.6.2 activity patterns were replicated by the greatest number of species (9) in autumn, in varying degrees. No species replicated all three patterns of seasonal activity. For three groups of calls - *T. australis*, the “unidentified group of calls”, and *Nyctophilus* spp. - there were no apparent replications of any TCA.6.2 seasonal patterns of activity.

6.2.5 ASSEMBLAGE SEASONAL AND NOCTURNAL PATTERNS OF ACTIVITY (Total call abundance)

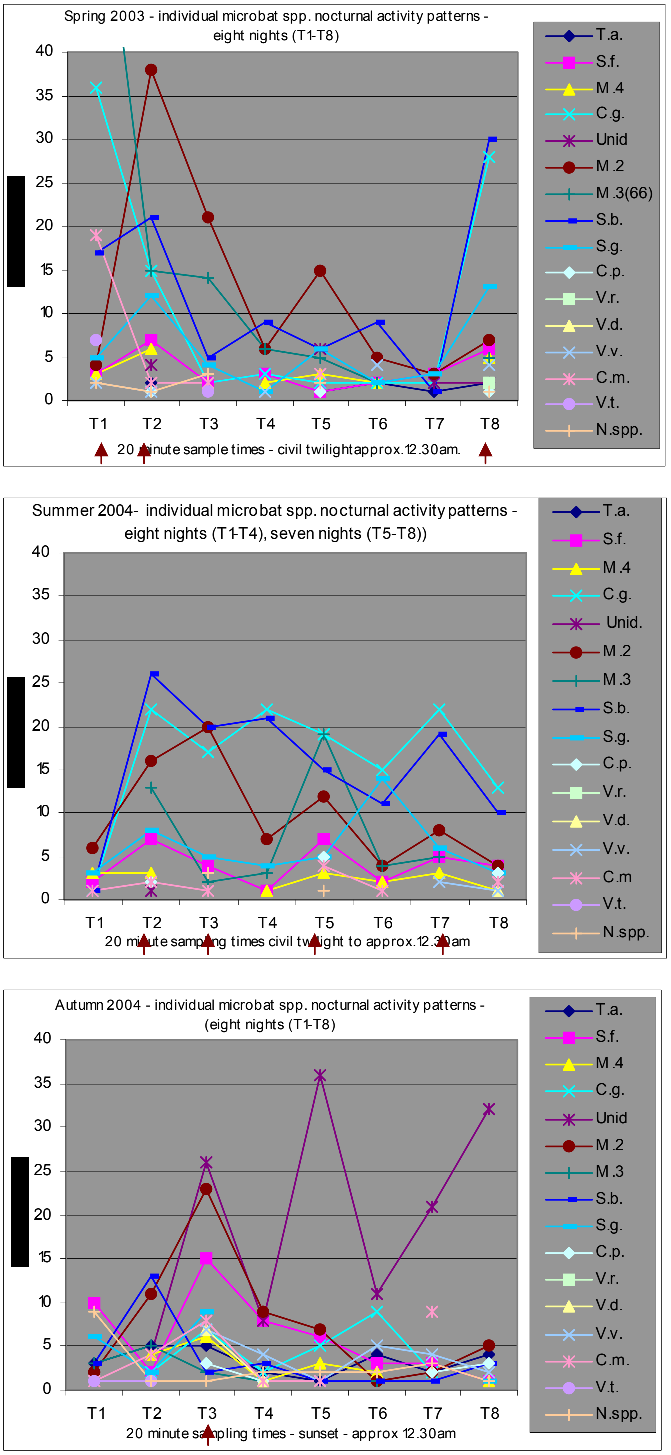
So far in this chapter seasonal and nocturnal patterns of activity have been examined for the total microbat assemblage, and for individual species separately. This section will combine these two sets of activity patterns to examine the contributions made by individual species to the overall assemblage pattern of activity (TCA.6.2).

Fig. 6.2d identifies the seasonal and nocturnal variations, and the interrelationships in patterns of total call abundance for the individual species within the assemblage framework. The result for each sample time represents a point in a pattern of activity for an individual species (Attachment 6.2), as well as a point in a pattern for the assemblage of species (TCA.6.2). For individual species, a point in the pattern can represent a peak, a trough, or a position somewhere between the two. For the assemblage, a point in the pattern represents a coincidence of similar or dissimilar patterns by groups of individual species. In Fig. 6.2d maroon arrow pointers represent the times of peaks in assemblage activity (TCA.6.2).

Comparisons of the assemblage nocturnal activity revealed complexities of interlinking patterns of activity and differences in seasonal interrelationships.

In spring, the sample times with a coincidence of high call activity for most species were T2 and T8. In summer the times where this coincidence occurred for most species occurred were T2 and T7, with another lower coincidence of activity in T5. The intervening sample times in summer showed a web of differing individual patterns of activity. In autumn only one sample time, T3, showed a coincidence of high levels of activity for most species. One group of calls in autumn displayed a completely different, erratic pattern of activity between T5 and T8.

Where the patterns of assemblage peaks in activity shown in TCA.6.2 were not matched by a coincidence of high activity by most species (i.e. spring T1, summer T5 and autumn T5), the differences were the result of a high number of calls recorded for only some species conforming to assemblage patterns, and not a coincidence of similar patterns by most species.



KEY

T.a.	*Tadarida australis*
S.f.	*Saccolaimus flaviventris*
M.4	*Mormopterus* sp. 4
C.g.	*Chalinolobus gouldii*
Unid.	Unidentified group of calls
M.2	*Mormopterus* sp. 2
M.3	*Mormopterus sp. 3*
S.b.	*Scotorepens balstoni*
S.g.	*Scotorepens greyii*
C.p.	*Chalinolobus picatus*
V.r.	*Vespadelus regulus*
V.d.	*Vespadelus darlingtoni*
V. v.	*Vespadelus vulturnus*
C.m.	*Chalinolobus morio*
V.t.	*Vespadelus troughtoni*
N. spp.	*Nyctophilus* spp.

Fig. 6.2.d. A comparison of seasonal and nocturnal patterns of activity (total call abundance) for individual species within the microbat assemblage (SSA03/04 surveys)

The coincidence of low levels of activity for all species occurred only in spring T7, summer T1, and with the exception of one species autumn T8. Other sample times where most species coincidentally showed reductions in activity were spring T3, summer T6 and T8, and autumn T4 and T7. This assemblage activity, with the exception of autumn T7, reflected in the patterns of TCA.6.2. The autumn T7 results were a reflection of the number of calls of species not conforming to the assemblage pattern.

The sampling times showing peaks in assemblage activity (marked with maroon arrows Fig. 6.2d) are composed of three differing contribution categories from individual species (i) species that are replicating peaks in TCA.6.2; (ii) species contributing a high call abundance from differing patterns of activity and not necessarily replicating a TCA.6.2 pattern; (iii) species contributing low call abundance from differing patterns of activity. Table 6.2d. details the type of pattern contribution, the species and the number of calls made to the assemblage activity peaks (TCA.6.2). Table 6.2e summarises this data. Column 1 sets out the assemblage contribution type. A low number of calls in category (i) can mean a replication of a TCA.6.2 peak but at a very low level of call activity.

Table 6.2.d. Categories of species' contributions to TCA 6.2 peaks in assemblage activity.

Con-tribution type	Spring				Summer			Autumn
	T1(173)	T2(129)	T5(51)	T8(112)	T2(113)	T5(103)	T7(80)	T3(137)
(i)	*M.*sp.3 (66) *C.g.* (36) *C.m.* (19) *V.t.* (7)	*M.*sp.2(38) *S.b.* (21) *S.g.* (12) *S.f.* (7) *M.*sp.4 (6) Unident.(4)	*M.*sp.2 (15) *S.g.* (6) Unident (6) *M.*sp.4 (3) *C.m.* (3)	*S.b.* (30) *C.g.* (28) *S.g.* (13) *M.*sp.2 (7) *S.f.* (6) *M.*sp.4 (5) *M.*sp.3 (5) *V.v.* (2)	*S.b.* (25) *C.g.* (19) *M.*sp.3 (13) *S.g.* (8) *S.f.*(7)	*M.*sp.3 (19) *M.* spp.2 (12) *S.f.* (7) *C.p.*(5) *C.m.* (4) *M.*sp.4 (3)	*C.g.* (22) *S.b.* (19) *M.*sp.2 (8) *S.f.* (5) *M.*sp.4 (3) *V.v.*(2)	Unident.(26) *M.*sp.2 (23) *S.f.* (15) *S.g.* (9) *C.m.* (8) *C.g.* (7) *V.d.* (7) *V.v.* (7) *M.*sp.4 (6) *C.p.* (3)
(ii)	*S.b.*(17)	*M.*sp.3 (15) *C.g.* (15)	*S.b.* (6)		*M.*sp.2 (11)	*C.g.* (19) *S.b.* (15)		
(iii)	*S.g.* (5) *M.*sp.2 (4) *S.f.* (3) *M.*sp.4 (3) *V.v.* (2) *N.* spp. (2)	*C.m.* (2) *T.a.* (2) *C.p.* (1) *V.v.* (1) *N.* spp. (1)	*M.*sp.3 (5) *C.g.* (2) *N.* spp.(2) *T.a.* (1) *S.f.* (1) *C.p.* (1)	*V.r.* (2), *T.a.* (2), C.p. (1), *N.* spp. (1)	*M.*sp.4 (3) *C.m.* (2) *V.v.* (2) *C.p.* unident (1)	*S.g.* (5) *N.* spp. (1)	*S.g.* (6) *M.*sp.3 (5)	*T.a.* (5) *S.b.* (2) *M.*sp.3 (2) *N.* spp.(1)
Total	**10+1g**	**12+1g**	**11+1g**	**11+1g**	**11**	**9+1g**	**8**	**13 + 1g**

KEY

Red	highest species richness contribution				
T.a.	*Tadarida australis*	M. sp. 3	*Mormopterus* sp. 3	V.v.	*Vespadelus vulturnus*
S.a.	*Saccolaimus flaviventris*	S.b.	*Scotorepens balstoni*	C.m.	*Chalinolobus morio*
M.sp.4	*Mormopterus* sp. 4	S.g.	*Scotorepens greyii*	V.t.	*Vespadelus troughtoni*
C.g.	*Chalinolobus gouldii*	C.p.	*Chalinolobus picatus*	N.spp	*Nyctophilus* spp.
Unid.	Unidentified group of calls	V.r.	*Vespadelus regulus*		
M. sp.2	*Mormopterus* sp. 2	V.d.	*Vespadelus darlingtoni*		

Table 6.2.e. Numbers of species and types of contribution to TCA 6.2 peaks in assemblage activity

SSA03/04 surveys	Spring				Summer			Autumn
Times (calls)	**T1(173)**	**T2(129)**	**T5(51)**	**T8(112)**	**T2(113)**	**T5(103)**	**T7(80)**	**T3(137)**
(i)	**4**	**6**	**5**	**8**	**5**	**6**	**6**	**10**
(ii)	**1**	**2**			**1**	**2**		
(iii)	**6**	**4+1g**	**5+1**	**3+1g**	**5**	**1+1g**	**2**	**3+1g**
Total .spp.	**10+1g**	**12+1g**	**11+1g**	**11+1g**	**11**	**9+1g**	**8**	**13 + 1g**

In summary, within the nocturnal and seasonal patterns of the recorded microbat assemblage presence across the cotton production landscape, the contributions to the visualised peaks of activity (TCA.6.2) varied both in species richness and call abundance and came from a variety of individual species patterns of nocturnal and seasonal activity. The highest species richness contributions to the assemblage pattern of peak activity (TCA.6.2) was recorded during spring T8 and autumn T3 sample times. The microbat presence therefore varied extensively both nocturnally and seasonally.

Emergence

Calls recorded within T1 - the first 20 minutes after civil twilight in spring and summer, or after sunset in autumn - would be expected to include short calls of bats emerging from roost sites. *Chalinolobus morio* is reported to be usually the first species to emerge in spring. Both *Chalinolobus gouldii* and *Scotorepens balstoni* are reported to emerge early at night to forage, *C. gouldii* often emerging while there is still extensive ambient light (Churchill 1998).

The results for sampling time T1 varied seasonally in both species composition and call abundance (Table 6.2f). Only in spring was extensive call activity recorded in T1. *C. gouldii* (36 calls), *S. balstoni* (17), *C. morio* (19) and *Mormopterus* sp. 3 (66) all recorded high call abundance in spring T1, but below three calls during T1 for summer and autumn. In summer T1 one call each was recorded for *S. balstoni*, *C. gouldii* and *C. morio*, and no calls for *Mormopterus* sp. 3; in autumn T1 three calls each were recorded for *S. balstoni* and *Mormopterus sp.* 3, one call for *C. morio* and zero for *C. gouldii.*

Although the call abundance for each species varied, calls were recorded for five of the assemblage species during T1 sample times in spring, summer and autumn - *S. balstoni*, *C. morio*, *Mormopterus* sp. 2, *S. greyii* and *S. flaviventris* (Table 6.2g). Three species were present during T1 in two seasons - *C. gouldii* and *Mormopterus* sp. 4 (spring and summer), and *Mormopterus* sp. 3 and *V. troughtoni* (spring and autumn). Three species were present during T1 in one season only – *V. vulturnus* and *Nyctophilus* spp. in spring, and *T. australis* in autumn. Three species, *C. picatus*, *V. regulus*, *V. darlingtoni*, and the

Table 6.2.f. Seasonal comparisons of species and calls recorded during T1 sampling sessions.

	Spring	**Summer**	**Autumn**
T1	*Mormopterus* sp.3 (66) *C. gouldii* (36) • *S. balstoni* (17) • *C. morio* (19) *V. troughtoni* (7) • *S. greyii* (5) • *Mormopterus* sp. 2 (4) *Mormopterus* sp. 4 (3) • *S. flaviventris* (3 *V. vulturnus* (2) *Nyctophilus* spp. (2)	• *Mormopterus* sp. 2 (6) • *S. greyii* (3) *Mormopterus* sp. 4 (3) • *S. flaviventris* (2) *C. gouldii* (1) • *S. balstoni* (1) • *C. morio* (1)	• *S. flaviventris* (10) • *S. greyii* (6) *T. australis* (3) *Mormopterus* sp. 3 (3) • *S. balstoni* (3) • *Mormopterus* spp. 2 (2) • *C. morio* (1) *V. troughtoni* (1)
Total	**10 spp. 1 genus**	**7 species**	**8 species**

KEY

•	recorded present in T1 during all three seasonal surveys		
T. australis	*Tadarida australis*	*S. balstoni*	*Scotorepens balstoni*
S. flaviventris	*Saccolaimus flaviventris*	*S. greyii*	*Scotorepens greyii*
M. sp. 4	*Mormopterus* sp. 4	*V. vulturnus*	*Vespadelus vulturnus*
C. gouldii	*Chalinolobus gouldii*	*C. morio*	*Chalinolobus morio*
M. sp. 2	*Mormopterus* sp. 2	*V. troughtoni*	*Vespadelus troughtoni*
M. sp. 3	*Mormopterus* sp. 3	*Nyctophilus* spp.	*Nyctophilus* spp.

"unidentified group of calls", were absent from all T1 emergent sampling times. During sample time T1 in spring, ten species and one genus were recorded; in summer seven species were recorded and in autumn, eight.

Pattern of activity for the unidentified group of calls in autumn

These calls are an anomaly and would appear to indicate either the presence of another species primarily in autumn or seasonal call variation for *C. gouldii* or *Mormopterus* sp.2.

6.2.6 DISCUSSION

With much microbat research conducted using remote full-night echolocation recording aimed primarily at the assessment of biodiversity, species diversity, or the ecology of individual species, little attention has been given to nocturnal and seasonal patterns of activity. Patterns of activity have been predominantly related to the behaviour of individual species and small groups of species for niche studies. Five previous studies having relevance for the present study are included below:

- Law *et al.* (1998) examined nightly activity patterns in hour blocks for each species in a survey within state forests on the South West slopes of NSW.

- Richards (2003) examined nocturnal activity patterns across three different case studies: (i) one species on Christmas Island; (i) one species at a coal mine in the Hunter Valley, NSW; and (iii) levels of activity at a gold mine near Orange, NSW. The results showed microbat presence at different habitat at different times of the night according to the characteristics of the site.

- Pavey *et al.* (2001) examined the benefits of twilight foraging for Schneider's leafnosed bat in Sri Lanka and found that twilight foraging comprised 47% of total foraging time. A wide diversity of prey was taken including large numbers of insects, only available or had marked peaks of abundance, during twilight.

- Lee & McCracken (2005) examined the food habits of one species at three colonies over three summers in Texas USA, and found that consumption of pest species varied by time of night and seasonally in relation to insect pest activity patterns.

- Lee and McCracken (2004) examined temporal height distribution of flight activity and food resource partitioning for three species where the three species occurred in sympatry. They found that foraging height and time varied when species activity patterns overlapped.

It is widely accepted that crepuscular peaks in microbat activity occur early (immediately after sunset) and late (before dawn). This behaviour is thought to be related to the swarming characteristics of many insect species, particularly Diptera, at dusk and prior to dawn (Jones & Rydell 2003), as well as the increase in the availability of both the prey range at the juncture of day and night, and the length of foraging time (Pavey *et al.* 2001).

The results for the study area assemblage reported in this chapter have demonstrated that patterns of activity for individual species, as well as an assemblage of species, vary nocturnally and seasonally. Specific landscape locations have also been shown to influence nocturnal and seasonal activity patterns. The variation between individual sites, individual species, assemblages of species at sites, sampling times, nights, and seasons, all result in extremely complex and seasonally varying sets of interrelationships.

This chapter establishes the framework for more questions – why the variations? Are they due to prey availability or prey activity, either insect or bat niche behaviour, or both, the seasonal variation of cropping systems, climatic conditions – or the combination of all. Some of these questions will be examined in the following chapters.

Many past studies have been conducted in forest or woodland landscapes. Foraging behaviour of a assemblage of microbats in an intensively managed cotton production landscape, accompanied by climatic conditions of high summer diurnal and low winter nocturnal temperatures, is likely to differ from other studies. Behaviour may be influenced by not only nocturnal variations in insect populations but also nightly patterns of insect behaviour associated with irrigated cropping infrastructure and systems, as well as irrigation river flows and their riparian interdependency (Baxter *et al*. 2005).

MICROBAT SPECIES INDEX

The results of this chapter would suggest that sampling microbat populations involves a complex set of considerations. From the examination of nocturnal and seasonal patterns of activity described in this chapter, a Microbat Species Index has been constructed (Table 6.2g). Autumn T3 provided the highest species richness, with spring T2 and T8 and autumn T4 the next highest in species richness. Most microbat sampling in the past has been conducted in spring. This index would suggest autumn should be considered.

Table 6.2.g. Microbat Activity Index

Seasonal survey	**Sampling time of night** Spring and autumn (civil twilight) autumn (sunset) to approx 12.30 am.							
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
Spring '03 (8 nights)	10 spp 1g	**11spp 1g 1unid**	8 spp 1g	8 spp	10 spp 1g 1unid	9 spp	6 spp 1 unid	**11 spp 1g 1 unid**
Summer '04 (7.5 nights)	8 spp	10 spp 1unid	7 spp 1g	7 spp	9 spp 1g	8 spp	8 spp	10 spp
Autumn '04 (8 nights)	8s	10s 1g 1unid	**12s 1g 1unid**	**11s 1g 1unid**	8s 1g 1unid	8s 1g 1unid	8s 1g 1unid	8s 1g 1unid

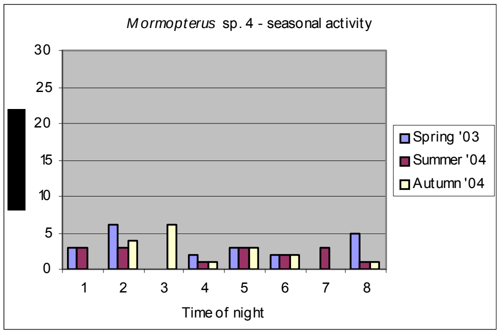
KEY (g) genus; (unid) unidentified group of calls

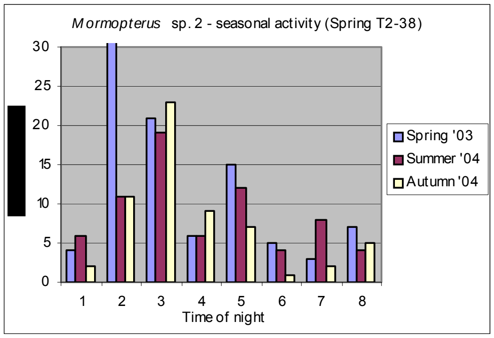
6.2.7 CONCLUSIONS

Although sampling effort could appear small high variability in bat activity has however been shown in this chapter. Mean of call abundance for sampling times varied between 2 and 21.6 calls, both recorded across spring night samples, and calls for individual species for sampling times varied from 66 to 2 (*Mormopterus* sp. 3) also in spring. The seasonal comparisons suggest that the majority of microbat species are active throughout the three seasons examined. Several species are possibly seasonal visitors. Although calls of *Tadarida australis* were recorded and heard extensively during the autumn Exploratory Survey, calls were neither heard nor recorded during the Summer Seasonal Survey. More's the pity as a species audible to humans, predating on moths, with research evidence of extensive *Tadarida* sp. predation on major cotton moths spp. in USA, a presence during summer cotton production could have provided an important flagship species to drive improved management of native vegetation remnants for roost sites. The activity comparisons further suggest that bat activity during the course of a night differs between species, and for different species between seasons.

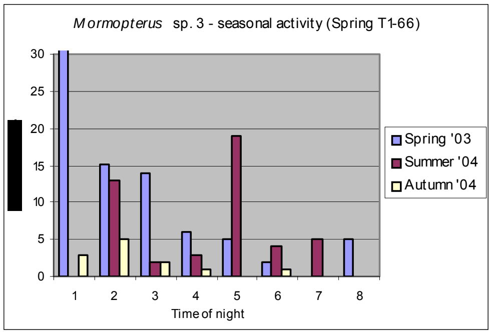
Table 6.2 Comparisons of seasonal and nocturnal patterns of activity for individual microbat species

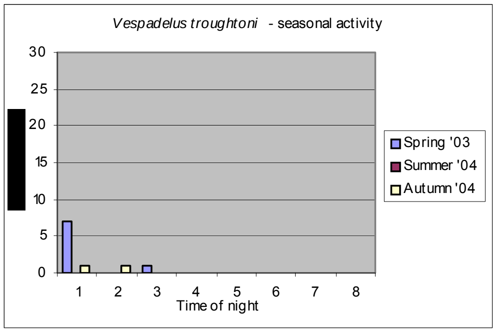
Even activity all seasons – variations in levels of activity & some spring predominance (*M.* sp. 2 - 38 calls recorded in spring T2)

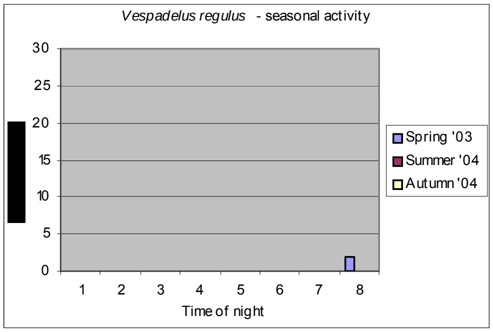




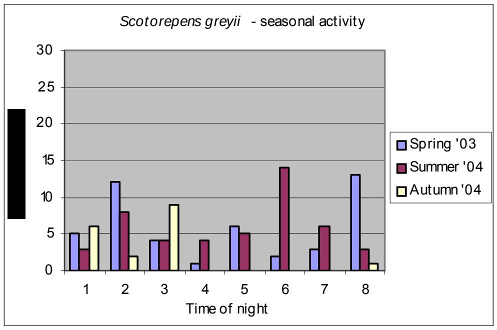
Strong spring predominance (*M.* sp. 3 - 66 calls in Spring T1)



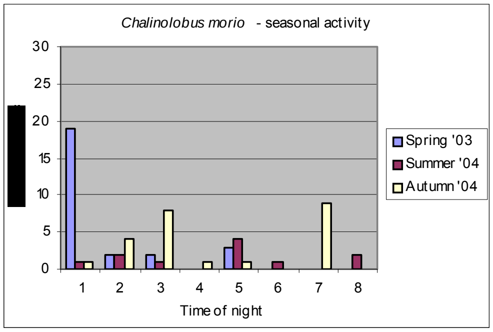




Summer and spring predominance



Spring and autumn predominance



Summer predominance (*S. balstoni* – 30 calls in Spring T8)

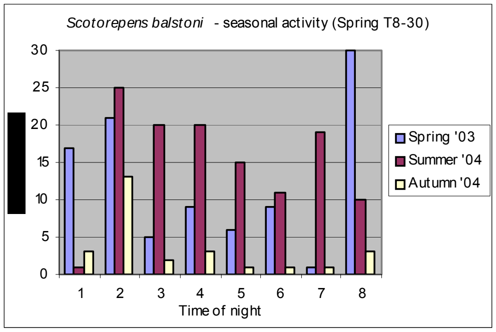
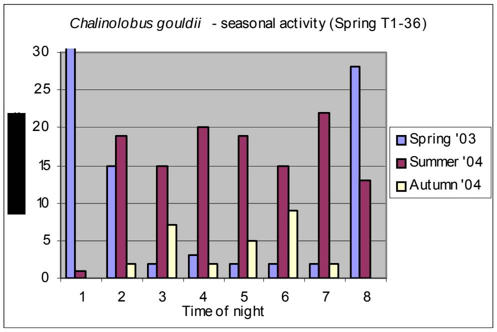
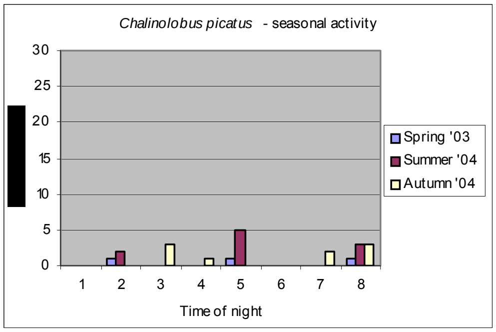


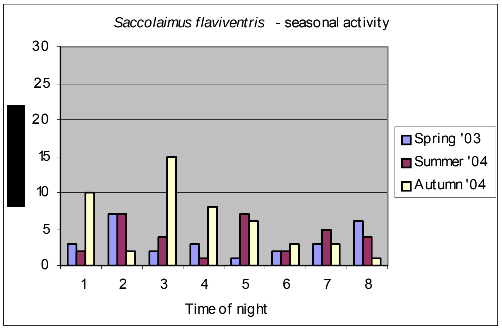
Table 6.2 Comparisons of seasonal and nocturnal patterns of activity for individual microbat species

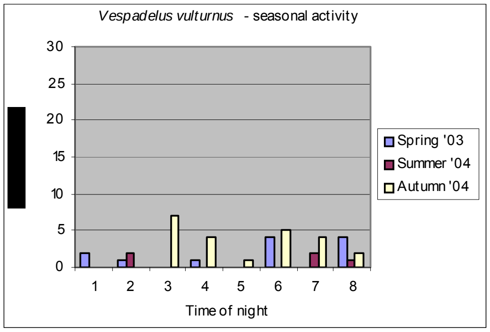
Summer dominance (contin.) (*C. gouldii* – 36 calls in Spring T1)

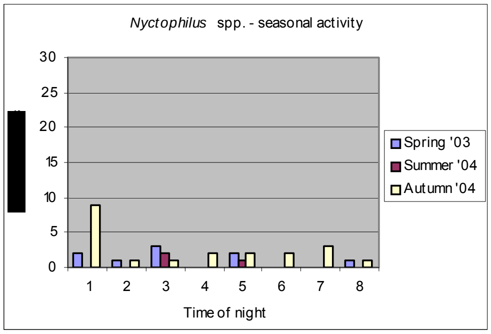

Chalinolobus gouldii - seasonal activity (Spring T1-36)

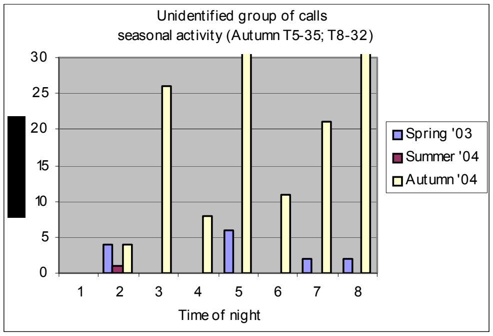

Chalinolobus picatus - seasonal activity

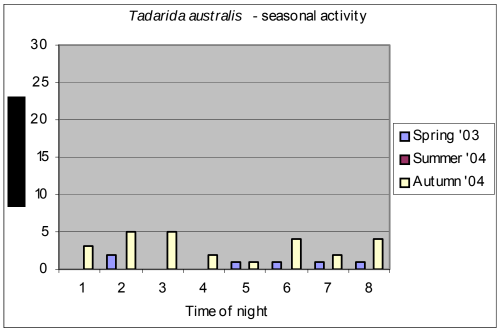
Activity all seasons with autumn predominance, or, activity with singularly autumn predominance (unid. calls - Autumn 35 calls T5; 32 in T8)

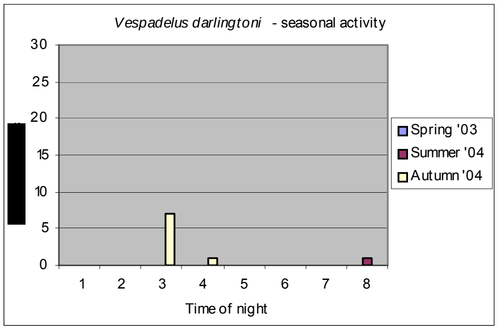

Saccolaimus flaviventris - seasonal activity


Vespadelus vulturnus - seasonal activity


Nyctophilus spp. - seasonal activity


Unidentified group of calls
seasonal activity (Autumn T5-35; T8-32)


Tadarida australis - seasonal activity


Vespadelus darlingtoni - seasonal activity

CHAPTER 6.3 MICROBAT PATTERNS IN FEEDING ACTIVITY

Chalinolobus morio (chocolate wattled) (Photograph Nicholas Birks - Wildflight)

Contents

INTRODUCTION

Microbats are among the most vocal of animals, and in some cases produce calls of over 200 ultrasonic echolocation pulses per second (Altringham and Fenton 2003). Calls might be emitted for positioning, maneuvering, social interaction or the detection and capture of prey, each activity reflected in the phase characteristics of the calls. The examination of different phases provides a means of investigating microbat activities. Alteration to calls when feeding results in a series of pulses increasing in slope, frequency and speed known as an "attack phase", which often culminates in a "feeding buzz". "Feeding buzzes" a dense concentration of short close pulses, provide unambiguous identification of foraging activities wether successful or not. The examination of call lengths provides a means of investigating possible impacts upon hearing insect activity. The longer the call the greater the possible impact upon the activities of hearing insect pests. This chapter will examine the call components associated with foraging and their nocturnal and seasonal utilisation.

6.3.1 LENGTH OF CALL

Calls may consist of only search phase pulses or, any combination of search, attack and feeding buzz phase pulses. Short calls may or may not end with a feeding buzz. Long calls may contain several attempts, some realized, at prey capture. Calls of longer duration during spring and summer cotton production may have a greater influence upon pest moth species avoidance behaviour (Roeder 1962/64, Rydell *et al.* 1995, Waters and Jones 1996, Acharya and McNeil 1998, Jones and Waters 2000) and consequent interference with moth nightly reproductive activities (Steins *et al.* 2003, Dillon *et al.* 2004, Greig and Greenfield 2004 and Svensson *et al.* 2004).

Seasonal distribution

Seasonal comparisons of total call abundance for five differing call lengths (Table 6.3a) showed that in spring there was a predominance of very long (>40 pulse) and long (21-40 pulse) calls, and in autumn there was a predominance of very short (1-5 pulse) and short (6-10 pulse) calls. In summer the highest concentration of calls were medium (11-20 pulse) calls, with the remaining call distribution generally declining from long, very short and short calls, to the lowest abundance for very long calls.

Table 6.3.a. Seasonal comparison of length of calls (red = highest)

Length of call	Spring	Summer	Autumn
>40 pulses (very long)	**155**	42	15
21-40 pulses (long)	**139**	132	73
11-20 pulses (medium)	121	**170**	114
6-10 pulses (short)	83	111	**140**
1-5 pulses (very short)	99	123	**162**

Nocturnal comparison of seasonal distribution

Total call abundance for five differing call lengths (Fig 6.3a), showed seasonal variation in the patterns of nocturnal call length distribution.

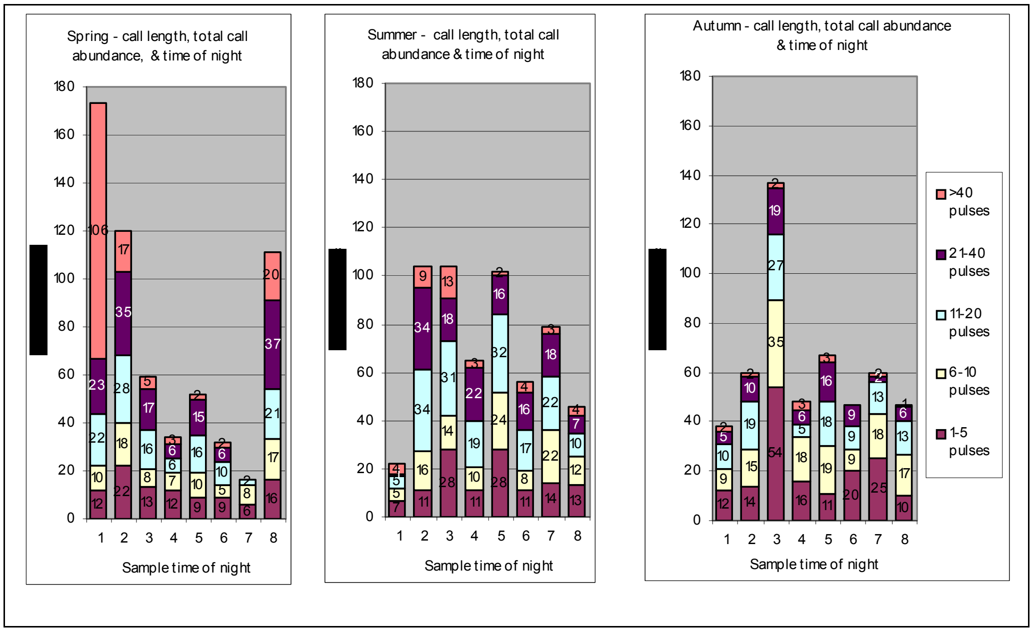


Fig. 6.3.a. Seasonal and nocturnal comparisons of total call abundance differentiated by length of call components

Very long (>40 pulse) calls were concentrated in five of the eight sample times recording peaks in assemblage activity. These were primarily in spring, predominantly in T1 - the sample time recording the highest assemblage total call abundance.   Long (21-40 pulse) calls concentrated in spring and summer, were predominantly in two spring and one summer sample times of peak assemblage activity. These sample times did not however include spring T1 of highest call abundance.   Medium (11-20 pulse) calls concentrated in summer were in the sample times of peak assemblage call abundance. Conversely short (6-10 pulse) calls concentrated in autumn and summer were in some of the sample times showing assemblage peaks in call abundance.   Although very short (1-5 pulse) calls were also concentrated in some autumn and summer peak times of assemblage call abundance, their distribution and intensity differed from that of short calls.

It would appear that the predominance of very long and long calls in spring could have resulted in interference to activities of hearing cotton pest moth species, however some of these results showed the influence of data from individual sites. The spring results during T1 included 101 very long calls recorded at a river gum forest site (Ca) and T8 included 30 long and 19 very long calls recorded at a poplar box site (Ea). If pest moths were active within vegetation remnants in spring at the beginning of the cotton production season long length of call could be of some importance. There is some evidence of movement for some insect species from vegetation remnants to cotton crops in spring (Rencken 2003a).

6.3.2 FEEDING BUZZ ABUNDANCE

Seasonal and nocturnal distribution

Total feeding buzz abundance varied both seasonally and nocturnally (Fig. 6.3b). From 338 in spring, total buzz abundance declined by 30% to 237 in summer, and by 65% to 117 in autumn. For spring 82% of total buzz abundance was recorded in, T1(120 buzzes), T8 (95), and T2 (64), for summer 38% was recorded in T2 (91), and in autumn the highest buzz score of 27 recorded in T3, constituted 23% of the total. The mean of sample time total feeding buzz abundance was 42.2 buzzes in spring, 29.6 in summer, and 14.6 in autumn.

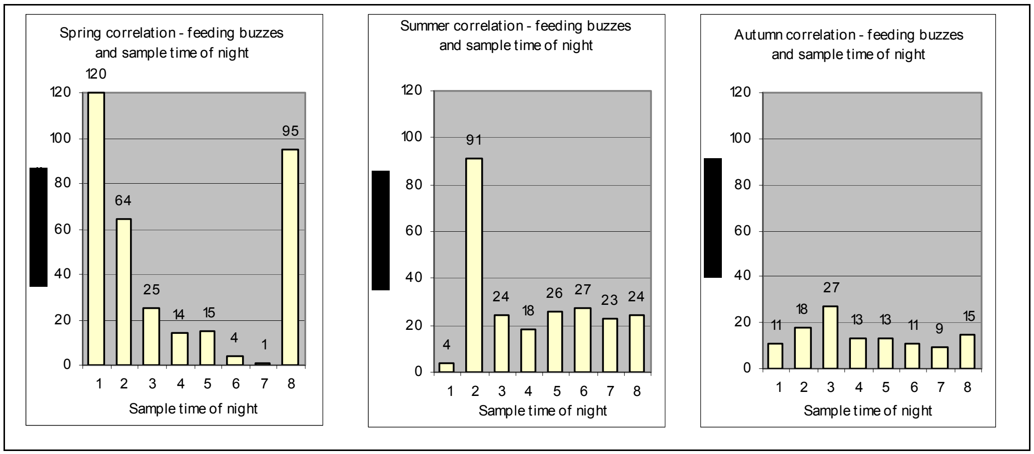


Fig. 6.3.b. Spring, summer and autumn comparisons of total feeding buzz abundance for each sample time of night

The distribution pattern of seasonal and nocturnal total feeding buzz abundance replicated patterns for total call abundance (Fig. 6.3a) in spring, and at a reduced intensity and variation in autumn. However the summer feeding buzz abundance pattern varied extensively from that of total call abundance. It comprised a singular high peak in feeding activity compared to the four lower peak pattern in call activity.

Maximum, mean and quartiles

An examination of the maximum, mean, median and quartiles for total feeding buzz abundance (Fig. 6.3c) reflected the distribution pattern for total feeding buzz abundance, as well as the influence of feeding buzz abundance data from individual sites.

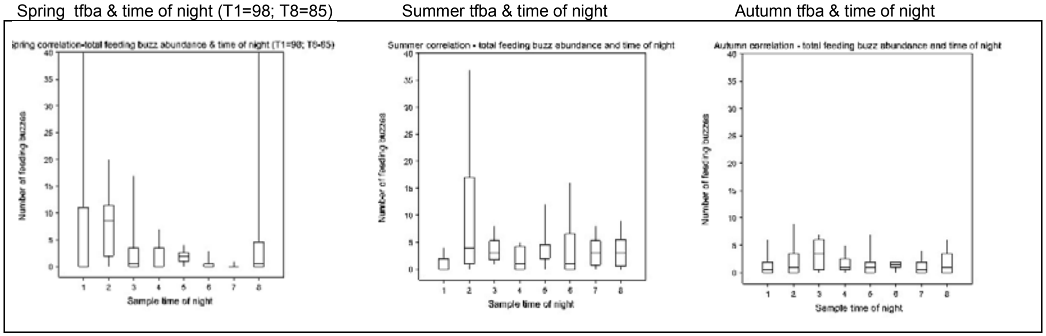

Spring tfba & time of night (T1=98; T8=85)
Summer tfba & time of night
Autumn tfba & time of night

Fig. 6.3.c. Spring, summer and autumn comparisons of total feeding buzzes for each sample time of night (Spring T1=98; T8=85)

Maximum feeding buzz abundance

Very high maximum feeding buzz abundance was recorded in two spring sample times T1(98 buzzes) and T8(85) and one summer time T2(37), and high maximum buzz abundance was recorded for spring T2(20), T3(19), and for summer T6(16) and T5(12). In autumn the highest of a much reduced maximum feeding buzz abundance was recorded in T2(9), T5(7), T1(6) and T3(6).

Mean and median of feeding buzz abundance

Three spring, one summer and one autumn sample times recorded high mean feeding buzz abundance, high mean standard error and low median scores, indicating a strong influence of the results from individual sites. In spring - in T1, 98% of buzz abundance was recorded at two sites – river gum forest site (Ca, 98 buzzes) and grey box site (Hi, 20); in T3, 68% of total buzz abundance (25) was recorded at an irrigated cropping site (Em), and in T8, 89% of the 95 buzz abundance was recorded at a poplar box site (Ea). In summer two mixed remnant sites (Cd, in T6), and (Gg, T5), respectively recorded 59% of 27 buzzes, and 46% of 26 buzzes. With a reduced autumn total feeding buzz abundance, in T2 50% of the 18 buzzes were recorded at a dryland cropping/roadside remnant site (Go).

One sample time each, in spring, summer and autumn, recorded high mean buzz abundance, lower mean standard error but high median, indicating inputs from a combination of sites. In spring time T2 the buzz abundance of 64 was a combination of results from mainly two irrigated cropping sites, Eh (20 buzzes) and Hb (11), and a mixed remnant site Cd (12). In summer T2 the 91 buzz abundance was a combination of results from predominantly four sites, a poplar box site Hg(37), a cypress pine site Gj (23), a grassland/isolated trees site Cl (15) and a water storage site Ar (9). With reduced buzz abundance in autumn the 27 buzz abundance recorded in sample time T3 was a combination of results from a cypress pine site Gj (7), two poplar box sites Ea and Cnn (6 buzzes each), and a river gum open forest site Ff (5).

6.3.3 FEEDING BUZZ AND CALL ABUNDANCE

Eight sample times that recorded the highest total call abundance (tca), four also recorded the highest total feeding buzz abundance (tfba) of between 64 and 120 (Fig. 6.3d). These sample times were spring T1, T2, T8 and summer T2. The other four sample times that recorded high call abundance (summer T3, T5, T7 and autumn T3) recorded lower feeding buzz abundance of between 23 and 27.

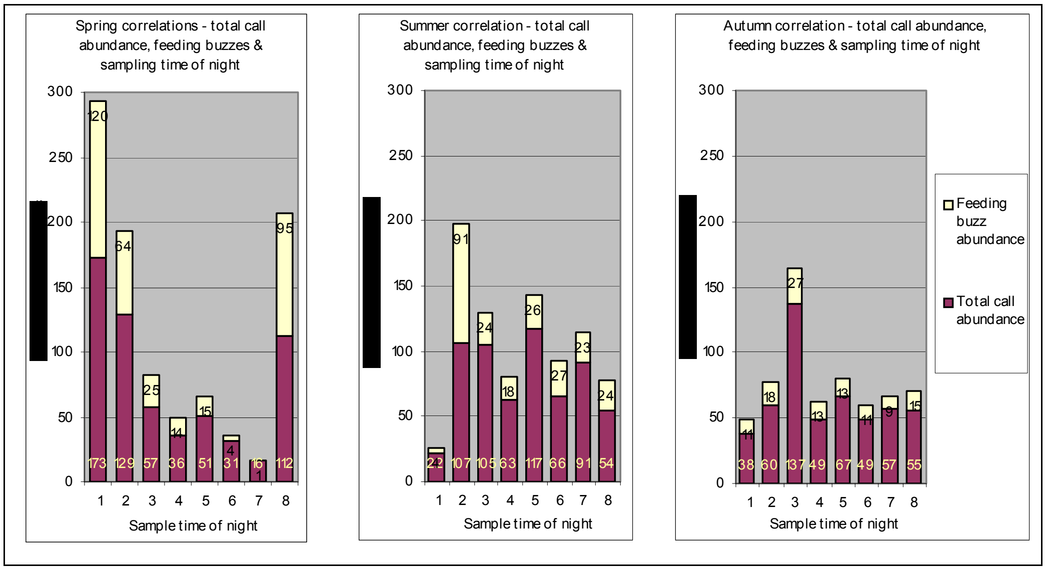


Fig. 6.3.d. Spring, summer and autumn comparisons of total feeding buzz abundance, total call abundance and sample time of night

Ratio - total feeding buzz abundance (tfba) to total call abundance (tca)

A seasonal comparison of total feeding buzz abundance to total call abundance, together with a calculated ratio for total feeding buzz to total call abundance (tfba/tca) shown as the number of buzzes per call, and an overall rating for each (tfba/tca) ratio, are set out in Table 6.3b.

Although both the highest total feeding buzz abundance (tfba) and total call abundance (tca) were recorded in spring sample time T1, higher ratios of feeding buzz to call (tfba/tca) were recorded in spring T8 (0.85 buzzes per call) and summer T2 (0.81) whereas the spring T1 ratio was 0.69 buzzes per call. Though recording the second highest total call abundance of 125, with fewer buzzes (64), the spring sample time T2 realised only the fourth highest tfba/tca ratio of 0.51 buzzes per call.

Table 6.3.b. Seasonal and nocturnal comparisons total feeding buzz and total call abundance ratio (red to yellow ratio ranking)

Season	Sample time	Total feeding buzz abundance	Total call abundance	Number of feeding buzzes per call	Highest/lowest tfba/tca ratio
Spring	**T1**	**120**	**173**	**0.69**	**3**
	T2	**64**	**125**	**0.51**	**4**
	T3	**25**	**57**	**0.44**	**6**
	T4	14	36	0.39	8
	T5	15	51	0.29	10
	T6	4	31	0.13	23
	T7	1	10	0.1	24
	T8	**95**	**112**	**0.85**	**1**
Summer	T1	4	18	0.22	18
	T2	**91**	**113**	**0.81**	**2**
	T3	24	91	0.26	16
	T4	18	63	0.29	10
	T5	26	103	0.25	17
	T6	27	62	0.44	6
	T7	23	80	0.29	10
	T8	**24**	**48**	**0.5**	**5**
Autumn	T1	11	38	0.29	10
	T2	18	60	0.3	9
	T3	27	137	0.20	20
	T4	13	49	0.27	14
	T5	13	67	0.19	21
	T6	11	49	0.22	18
	T7	9	57	0.16	22
	T8	15	55	0.27	14

Some sample times with low to medium total call abundance and a proportionally high feeding buzz abundance realised a high feeding buzz to call ratio - summer T8 (24 buzzes for 48 calls, 0.5 buzzes per call), summer T6 (27, 62) and spring T3 (25, 57) both with 0.44 buzzes per call, and spring T4 (14, 36, 0.39).

Some sample times with high call abundance but low feeding buzz abundance realised lower buzz to call ratios - autumn T3 (27, 137, 0.20), summer T5 (26, 103, 0.25), and summer T3 (24, 91, 0.26).

Seasonal Buzz/Call Mean Ratio

The overall seasonal mean for the ratio of total feeding buzz abundance to total call abundance (tfba/tca) was 0.43 buzzes per call in spring, 0.30 in summer and 0.23 in autumn.

6.3.4 FEEDING BUZZ AND LENGTH OF CALL

Seasonal variation occurred in the reelationships between total feeding buzz abundance and length of call (Fig 6.3.g). There was a very strong relationship between feeding buzz and long calls in all seasons as the vector lines for total feeding buzz abundance and long (21-40 pulse) calls were (very close). Very long (>40 pulse) calls showed the next strongest relationship in spring and summer, however in autumn both medium (11-20 pulse) and short (6-10 pulse) calls showed stronger relationships to feeding buzz abundance than very long calls. Medium calls were more closely related to total feeding buzz abundance in spring than in summer. The calls showing the least related with total feeding buzz abundance were very short (1-5 pulse) calls in spring and autumn, and in summer short calls, closely followed by very short calls.

Three categories of feeding buzz were recorded: (i) from within overlapping and continuous calls by a combination of species, (ii) associated with long individual calls, (iii) at the termination of some short calls.

The links between the seasonal distribution of call lengths and feeding buzzes were realized at individual sites using a ratio of number of feeding buzzes per minute. In spring the maximum ratio of 5.15 feeding buzzes per minute was recorded at a river gum forest site (Ca, T1) where 101 of the 134 calls recorded were very long calls. In summer the maximum ratio of 2 buzzes per minute was recorded at a poplar box site (Hg, T2) where the calls were predominantly long calls, with some medium length calls. The autumn maximum ratio of 0.5 buzzes per minute was recorded at a dryland cropping site adjacent to a roadside remnant (Go, T2). These calls were composed of a call mixture (in order from highest to lowest call abundance) of medium, very short and long calls.

6.3.5 SPECIES AND FEEDING BUZZ ABUNDANCE

An examination of feeding buzzes recorded for individual microbat species showed both interspecific and seasonal variation (Fig. 6.3e).

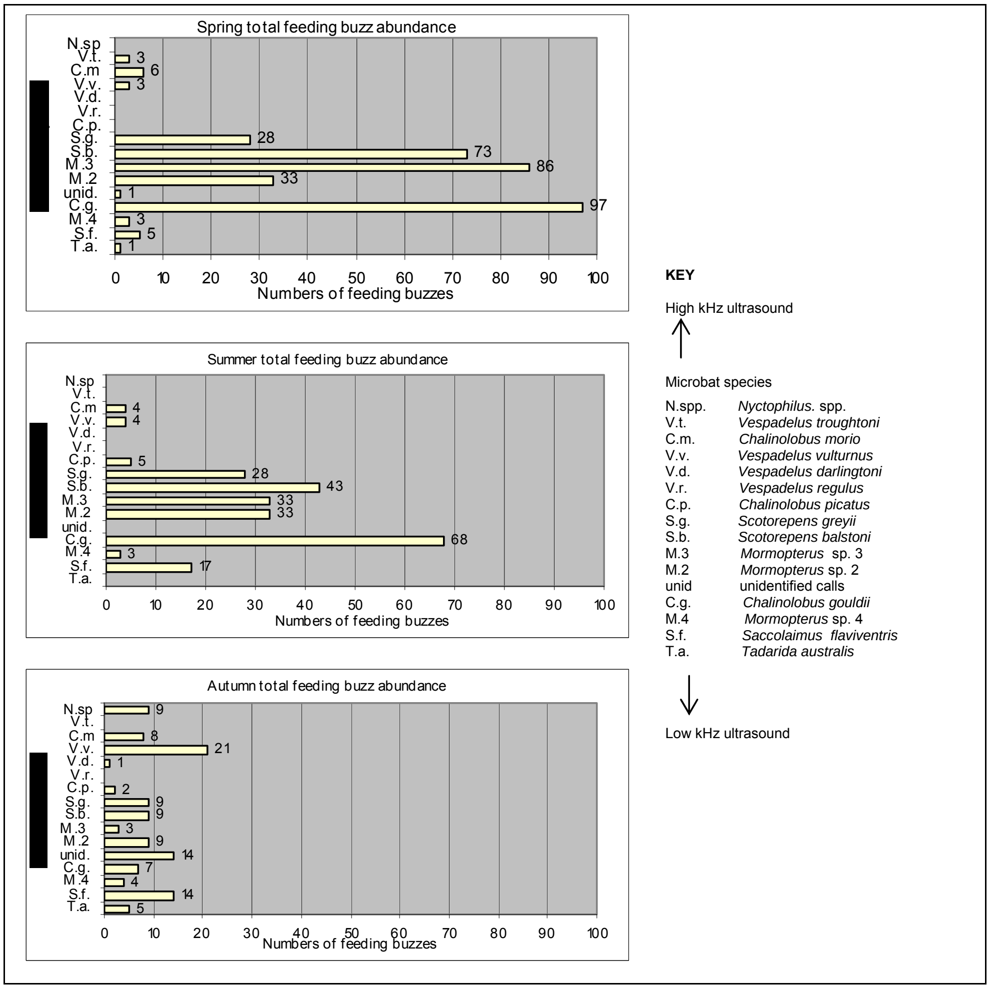


Fig. 6.3.e. Seasonal comparison of total feeding buzz abundance for individual microbat species

In spring and summer although the same five species recorded 90% of total feeding buzz abundance and the same single species dominated buzz abundance recording 28% and 29% in spring and summer respectively, the intensity of buzz abundance varied between the other four species. The autumn results were however much lower in abundance and more evenly distributed. Three different species recorded 40% of autumn feeding buzz abundance with the remaining 60% distributed across nine species.

Seasonal and interspecific variation in feeding buzz abundance

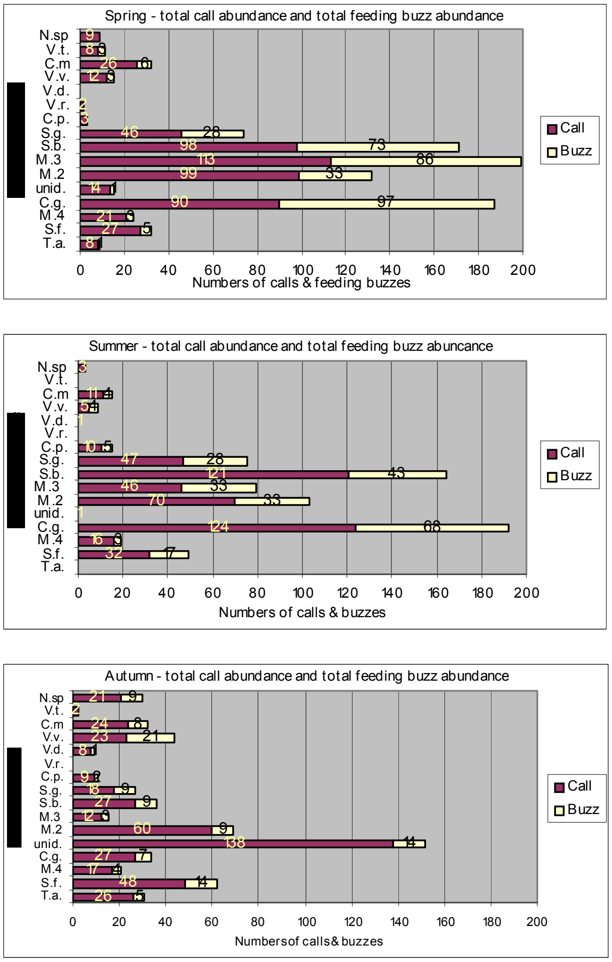
In spring three species recorded very high total feeding buzz abundance: *C. gouldii* (97), *Mormopterus* sp. 3 (86), and *S. balstoni* (73). Two species, *Mormopterus* sp. 2 and *S. greyii*, recorded buzz abundance of 33 and 28 respectively. Seven species recorded buzz abundance between 6 and 1: *C. morio*, *S. flaviventris*, *Vespadelus troughtoni*, *V. vulturnus*, *Mormopterus* sp. 4, *Tadarida australis* and the “unidentified group of calls”.

In summer there was change in both total buzz abundance and the species that recorded high buzz abundance. Again *C. gouldii* recorded the highest buzz abundance (68), however the next highest was *S. balstoni* (43). Three species repeated the spring results: *Mormopterus* sp. 2 and sp. 3 recorded 33 and *S greyii* recorded 28. *S. flaviventries* recorded 17 compared to 5 in spring. *C. morio*, *V. vulturnus* and *Mormopterus* sp. 4 all recorded similarly low buzz abundance as in spring, and *Chalinolobus picatus* recorded 5. There were no buzzes recorded for *Nyctophilus* spp. in spring or summer.

The autumn results were very different. The highest feeding buzz abundance was recorded for *V. vulturnus* (21) compared to 3 and 4 in spring and summer. *S. flaviventris* and the “unidentified group of calls” both recorded 14 autumn buzzes compared to 5 and 17 and 1 and 0 respectively in spring and summer. Four species recorded 9: *Mormopterus* sp. 2, *S. balstoni*, *S. greyii* and *Nyctophilus* spp. Seven species recorded between 8 and 1: *C. morio*, *C. gouldii*, *T. australis*, *Mormopterus* sp. 4, *Mormopterus* sp. 3, *C. picatus* and *V. darlingtoni*. For *C. gouldii* the autumn feeding buzz abundance of 7 differed greatly from 97 and 68 in spring and summer.

6.3.6 SPECIES - FEEDING BUZZ AND CALL ABUNDANCE

Fig. 6.3f combines the total feeding buzz abundance and the total call abundance for individual species within seasons. The relationships between total feeding buzz abundance and total call abundance varied between species and between seasons.



KEY

High kHz ultrasound ↑

Microbat species

N.spp.	*Nyctophilus.* spp.
V.t.	*Vespadelus troughtoni*
C.m.	*Chalinolobus morio*
V.v.	*Vespadelus vulturnus*
V.d.	*Vespadelus darlingtoni*
V.r.	*Vespadelus regulus*
C.p.	*Chalinolobus picatus*
S.g.	*Scotorepens greyii*
S.b.	*Scotorepens balstoni*
M.3	*Mormopterus* sp. 3
M.2	*Mormopterus* sp. 2
unid	unidentified calls
C.g.	*Chalinolobus gouldii*
M.4	*Mormopterus* sp. 4
S.f.	*Saccolaimus flaviventris*
T.a.	*Tadarida australis*

↓ Low kHz ultrasound

Fig. 6.3.f. Seasonal comparisons of total call abundance and total feeding buzz abundance for individual species.

Table 6.3c documents for each season and individual species (column 1), the total feeding buzz abundance (columns 2, 6, 10), the total call abundance (col. 3, 7, 11), the ratio calculated for total feeding buzz abundance to total call abundance expressed as buzz per call (col. 4, 8, 12), and a tfba/tca ratio ranking for each season (col. 5, 9 and 13).

Intraspecific variation

Seasonal variation in tfba/tca ratio occurred for all species. The season of highest ratio was spring for *S. greyii*, *S. balstoni*, *Mormopterus* sp. 3 and *C. gouldii*; summer for *C. morio*, *C. picatus*, *Mormopterus* sp. 2 and *S. flaviventris*; and autumn for *Nyctophilus* spp., *V. vulturnus*, *Mormopterus* sp. 4, *T. australis*, and the "unidentified group of calls".

Table 6.3.c. Seasonal comparisons of total feeding buzz abundance (tfba), total call abundance (tca), feeding buzz to call ratio (buzz per call) and tfba/tca ratio ranking. (a) absent; (red to yellow) ranking order

Species	Spring				Summer				Autumn			
	tfba	tca	**buzz per call**	tfba/ tca rank	tfba	tca	**buzz per call**	tfba/ tca rank	tfba	tca	**buzz per call**	tfba/ tca rank
Nyctophilus spp.	0	9	**0**	-	0	3	**0**	-	9	21	**0.42**	3
Vespadelus troughtoni	3	8	**0.75**	3	a	a	**a**	-	0	2	**0**	-
Chalinolobus morio	6	26	**0.23**	8	4	11	**0.36**	8	8	24	**0.33**	4
Vespadelus vulturnus	3	12	**0.25**	7	4	5	**0.80**	1	21	23	**0.91**	1
Vespadelus darlingtoni	a	a	**a**	-	0	1	**0**	-	1	8	**0.13**	13
Vespadelus regulus	0	2	**0**	-	a	a	**a**	-	a	a	**a**	-
Chalinolobus picatus	0	3	**0**	-	5	10	**0.50**	6	2	9	**0.22**	10
Scotorepens greyii	28	45	**0.62**	5	28	47	**0.59**	3	9	18	**0.50**	2
Scotorepens balstoni	73	98	**0.74**	4	43	121	**0.35**	9	9	27	**0.33**	4
Mormopterus sp. 3	86	113	**0.76**	2	33	46	**0.72**	2	3	12	**0.25**	8
Mormopterus sp. 2	33	99	**0.33**	6	33	70	**0.47**	7	9	60	**0.15**	12
unidentified calls	1	14	**0.07**	11	0	1	**0**	-	14	138	**0.10**	14
Chalinolobus gouldii	97	90	**1.08**	1	68	124	**0.55**	3	7	27	**0.26**	7
Mormopterus sp. 4	3	21	**0.14**	10	3	16	**0.19**	10	4	17	**0.24**	9
Saccolaimus flaviventris	5	27	**0.18**	9	17	32	**0.53**	5	14	48	**0.29**	6
Tadarida australis	0	8	**0**	-	a	a	**a**	-	5	26	**0.19**	11

The most consistent seasonal tfba/tca ratio results were recorded for *C. morio* (0.23 spring buzzes per call, 0.36 summer, 0.33 autumn), *S. greyii* (0.62, 0.59, 0.5), and *Mormopterus* sp. 4 (0.14, 0.19, 0.24). Greater seasonal ratio variations was recorded for *Mormopterus* sp. 2 (0.33, 0.47, 0.15), *S. flaviventris* (0.18, 0.53, 0.29) and *S. balstoni* (0.74, 0.35, 0.33), and the “unidentified group of calls” (0.07, 0, 0.10).

Although high ratios were recorded by individual species in individual seasons, either seasonal absence, absence of feeding buzzes, or extreme seasonal variation resulted in seasonal inconsistency in ratio results for *C. gouldii* (1.08, 0.55, 0.26), *V. vulturnus* (0.25, 0.8, 0.91), *Mormopterus* sp. 3 (0.76, 0.72, 0.25), *V. troughtoni* (0.75, a, 0), *C. picatus* (0, 0.5, 0.22), and *Nyctophilus* spp. (0, 0, 0.42). Seasonal absence and absence of feeding buzzes accounted for low ratios for *T. australis* (0, absent, 0.19), *V. darlingtoni* (absent, 0, 0.13) and *V. regulus* (0, absent, absent)

Interspecific variation

The ratios of total feeding buzz abundance to total call abundance were realised in different ways.

Some species recorded high total call abundance as well as high feeding buzz abundance resulting in a high tfba/tca ratio. In spring these species were *C. gouldii* (97 buzzes, 90 calls, 1.08 buzz per call), *Mormopterus* sp. 3 (86, 113, 0.76), *S. balstoni* (73, 98, 0.74), in summer *C. gouldii* (68, 124, 0.55), and no species in autumn.

Although high total call abundance was recorded, due to much lower feeding buzz abundance, low ratios were realised for some species. These included one species in spring – *Mormopterus* sp. 2. (33, 99, 0.33), two in summer - *Mormopterus* sp. 2 (33, 70, 0.47), *S. balstoni* (43, 121, 0.35), and three in autumn - *S. flaviventris* (14, 48, 0.29), *Mormopterus* sp. 2 (9, 60, 0.15) and the "group of unidentified calls" (14, 138, 0.10).

Low call abundance combined with high feeding buzz abundance realised a high ratio for some species. These species included two in spring - *V. troughtoni* (3, 8, 0.37) *S. greyii* (28, 45, 0.62); four in summer - *V. vulturnus* (4, 5, 0.8), *Mormopterus* sp. 3 (33, 46, 0.72), *S. greyii* (28, 47, 0.59), and *S. flaviventris* (17, 32, 0.53); and five in autumn - *V. vulturnus* (21, 23, 0.91), *S. greyii* (9, 18, 0.5), *Nyctophilus* spp. (9, 21, 0.42), *C. morio* (8, 24, 0.33) and *S. balstoni* (9, 27, 0.33)

The species recording the highest tfba/tca ratios were in spring *C. gouldii* (1.08 buzz per call), *Mormopterus* sp. 3 (0.76), *V. troughtoni* (0.75), *S. balstoni* (0.74), and *Mormopterus* sp. 2 (0.33); in summer *V. vulturnus* (0.8), *Mormopterus* sp. 3 (0.72), *S. greyii* (0.59), *C. gouldii* (0.55), *S. flaviventris* (0.53), *Mormopterus* sp. 2 (0.47) and *S. balstoni* (0.35); and in autumn *V. vulturnus* (0.91), *S. greyii* (0.5), *Nyctophilus* spp. (0.42), *C. morio* (0.33), *S. balstoni* (0.33), *S. flaviventris* (0.29), *Mormopterus* sp.2 (0.15), and "unidentified group of calls" (0.10).

Both *Mormopterus* sp. 2 and *S. balstoni* recorded high ratios in all seasons, as did *C. gouldii* and *Mormopterus* sp. 3 in spring and summer, and *S. flaviventris*, *V. vulturnus* and *S. greyii* in summer and autumn. One species in spring (*V. troughtoni)* and three in autumn (*Nyctophilus* spp., *C. morio*, "unidentified group of calls") recorded high ratios for one season only.

6.3.7 DISCUSSION

Although the "search" and "feeding buzz" phases of calls have respectively been utilised by researchers in identifying microbat species and feeding success, little research has focused on some other aspects of microbat calls. By examining the relationships between calls, feeding buzzes and call length, this chapter has shown that there are nocturnal, seasonal and spatial variations in foraging strategies, foraging effort and probably foraging success. It has also been shown that interspecific and intraspecific seasonal variation in these activities occurs. The impact of microbat presence indicated by the call length, and not necessarily feeding buzz success, could be the principal factor determining the behaviour of hearing insects and therefore the impact on peat insect reproduction and consequently pest insect populations. In Dillon *et al.* (2001) changes in moth behaviour, were observed long before a call was recorded with the Anabat recorder. The same modifications to moth behaviour were also observed in the absence of a call ie. the range of microbat impact on moth avoidance behaviour appeared to be very extensive, the distances of which were not be quantified. Dillon's uncompleted work focused primarily upon fluctuations in and the nature of, *Helicoverpa* nocturnal activities.

The results for two sets of calls need some explanation. *Nyctophilus* species utilise sight and hearing as well as ultrasound echolocation. It may be that calls for these species were predominantly feeding buzzes. Feeding buzzes were identified in autumn for this group of calls but not in spring and summer. The unidentified group of calls utilising an ultrasound frequency range fitting within the *Chalinolobus gouldii* and *Mormopterus* sp. 2 ranges could be calls of either species, or another species only present in autumn. With the highest total call abundance (138 calls) for any species in autumn, this group of calls recorded a very low number of feeding buzzes (14) resulting in a tfba/tca ratio of 0.10 buzz per call. Many of these calls contained combinations of frequencies and shapes differing from any other group of calls recorded.

An index of feeding buzz activity has been included in Table 6.3d. Although not recording the highest total call abundance, spring sample time T8 realised the highest ratio of total feeding buzz abundance to total call abundance. Summer T2 realised the second highest score for tfba/tca ratio, followed by spring T1. Although recording not as many calls as T3 in summer and autumn, sample times summer T8, spring T3 and T4 and autumn T2 and T1 all recorded higher tfba/tca ratios.

FEEDING BUZZ INDEX

Table 6.3.d. Seasonal index of microbat total feeding buzz abundance (tfba), total call abundance (tca), and tfba/ tca ratio ranking (1-10)

Seasonal survey	Sample time - civil twilight (spring & summer), sunset (autumn), to approx 12.30am.						
	T1	T2	T3	T4	T5	T6	&7	T8
Spring	■■◊◊ **(3)**	■◊ (4)	(6)	(8)				■■◊ **(1)**
Summer		■■◊ **(2)**	◊		◊ (6)			(5)
Autumn	(10)	(9)	◊					

KEY ■■ 90-120 tot feeding buzz abund; ■ 64 tot feeding buzz abund; ◊◊ 173 tol call abund; ◊ 90-137 tot call abund.

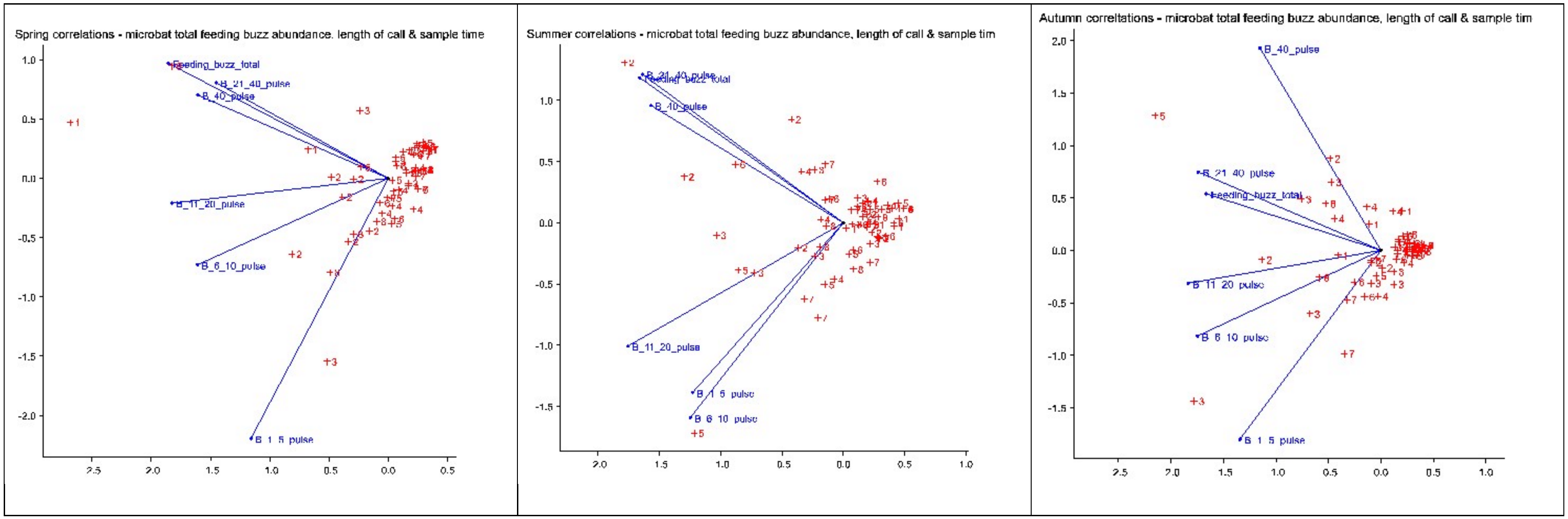


Fig. 6.3.g. Seasonal comparisons (and nocturnal) of correlations between microbat total feeding buzz abundance, microbat length of call (& sample time of night) indicated by the individual legth of call vectors in proximity to or distance from the feeding buzz total vector.

Chapter 6.4 INSECTS AND PREDATOR-PREY RELATIONSHIPS

Chapter 6.5 THE INFLUENCE OF CLIMATE, MOON AND OTHER VARIABLES

These chapters have been excluded from the body of the thesis due to their inconclusive and speculative results. However because of their significance for both microbat ecology and the cotton industry they have been included as Addendum A and B on the accompanying CD.

CHAPTER 6.6 STRUCTURING MICROBAT COMMUNITIES

Contents:

INTRODUCTION

In the past scientists have developed a considerable array of approaches to group microbat species according to morphology and behaviour. Whilst sometimes groupings have been related to ultrasound frequencies, none have used ultrasound as a single grouping entity. Although ultrasound frequencies are indicative of a complexity of factors, for this study examining microbats and their relationships to sonar sensitive insects some of which are pests to cotton crops, groupings are primarily based upon ranges of ultrasound either within or outside the range of insect sonar perception.

The species identified in the study area were examined against past guild classifications and then grouped into guilds based on the echolocation frequency used and the known ranges of frequencies that are audible to hearing insects. Microbat frequency ranges were determined from release calls recorded for some species during the Spring 2003 Harp trap survey, as well as from Pennay *et al.* (2004). Parameters from literature including foraging areas and prey preferences were assessed to establish a foundation for examining the landscape distribution and utilisation within the study area by the microbat assemblage in Chapter 6.7.

6.6.1 FINDING A SUITABLE GUILD STRUCTURE

Previous guild structures

Microbat assemblages have previously been divided into functional groups or guilds based on flight, speed and maneuverability and foraging patterns, linked to wing morphology and or aspect ratio and wing loading (O'Neill and Taylor 1986, Aldridge and Rautenbach 1987, Schumm *et al.* 1991, Fullard *et al.* 1991, Kutt 1995, Jennings *et al*. 2004, Canals *et al.* 2005). More recently with improved technology, groupings have linked ultrasound frequencies to, microbat body size and prey size (Bogdanowicz *et al.* 1999), foraging spaces based on vegetation clutter (de Oliveira 1998, Herr 1998, Korine and Pinshow 2004), and prey size detection (Herr 1998, Seimers and Schnitzler 2004).

By observing the flight patterns of pairs of Tasmanian microbat species, O'Neill and Taylor (1986) identified four distinct flight patterns based on speed, maneuverability and proximity to vegetation (Table 6.6a). The observed species included seven of the species identified in the research area.

Table 6.6.a. Groups of microbat species based on flight and foraging patterns (O'Neill and Taylor 1986)

Group	Flight and foraging patterns	Microbat species
A	faster, most direct flight, limited manoeuvreability, prefer open areas	*Chalinolobus goudii*
B	fast, direct, less manoeuvreable than smaller *Eptesicus* and fly higher	*Eptesicus sagittula* – synonyms *Vespadelus darlingtoni*, and *Chalinolobus morio*
C	highly maneuverable, faster than *Nyctophilus*, further from vegetation	*Vespadelas vulturnus* and *Vespadelus regulus*
D	slowest flight, undulating, closest to vegetation	*N. geoffroyi* and *N. timoriensis*

Herr (1998) classified an assemblage of south-eastern Australian microbats into four guilds (after O'Neill and Taylor 1986, Dwyer 1965, O'Neill and Taylor 1989, Fullard *et al.* 1991, and Kutt 1995), based on flight speed, maneuverability, and proximity to vegetation linked to ultrasound frequencies. These classifications combined two of O'Neill's and Taylor's (1986) classifications (B and C) and added an "above canopy" category linked to CF call type. Nine of the research area species were included.

Table 6.6.b. Groups of species based on flight and patterns and ultrasound frequency and call type (Herr 1998).

Guild	Foraging pattern	Flight pattern	Microbat species	Ultrasound characteristics
A	above canopy & in large gaps within canopy	fast flying aerial feeder, low manoeuvreability	*Tadarida australis** *Momopterus planiceps**	mainly CF calls, but also FM frequencies depending on the foraging habitat
B (O&T - A)	in canopy gaps and open spaces	medium-high speed, low-medium manoeuvreability	*Chalinolobus gouldii*	minimum frequency 28-32 kHz, overlap partly with *M. planiceps* FM calls with sometimes extended CF
C (O&T – B+C)	close to vegetation, below, inside and beside the canopy and sub-canopy	medium-high speed, medium-high manoeuvreability	*Vespadelus darlingtoni* *V. regulus,* *V. vulturnus* *Chalinolobus morio*	frequency overlaps: *V. regulus* and *V. vulturnus* (Fmin: 42-50kHz), with *V. darlingtoni* (F.min: 38-42 kHz); *V. regulus* and *V. vulturnus* with *C. morio* (Fmin: 49-54kHz); Preferences for prey size: overlap for all three *Vespadelus* spp. & *C. morio*
D (O&T-D)	glean from structures and forages close to and within the vegetation	low speed, highly manoeuvreable, ambush and gleaning strategy	*Nyctophilus geoffroyi,* *N. gouldi**	broad range FM call often without distinct CF portion.

* additional species to O'Neill and Taylor (1986)

Note: The Guild classification in column 1 includes group classifications by O'Neill and Taylor (1986) from Table 6.6.a.

De Oliveira (1998) classified groups of microbats into five categories, based on flight speed and maneuverability, as well as wing length and shape, ultrasound frequency, call type and foraging niche suitability (Table 6.6c). Although more comprehensive than either O'Neill and Taylor (1986) or Herr (1998) (Tables 6.6a and b), there are as many similarities (A, B, and D) as dissimilarities (C and E) in the categories used by de Oliveira (1998).

Table 6.6.c. Species grouped by foraging pattern, wing morphology, ultrasound frequency & type, and habitat suitability De Oliveira (1998)

Group	Forage/pattern	Flight pattern	Wing shape & species	Ultrasound freq.	Freq.type	Suited to
A	well above canopy height	high speed, low manoeuvreability, long flights	long narrow wings: eg. freetail (Molossid)	lower than (10kHz to 30kHz)	CF	hunting in open space
B	just above canopy height	high speed, medium manoeuvreability	narrow wings: eg. Gould's wattled (*Chalinolobus gouldii*)	medium frequency (>30kHz but <50kHz) varying in freq. over time	FM	
C	within vegetation gaps	moderate speed, high manoeuvreability	broad wings: eg. broadnosed (*Scotorepens* spp.)	medium frequency varying over time		hunting in the presence of obstacles
D	among vegetation and below canopy	low speed, extreme manoeuvreability,	Short & broad wings: eg. long-eared (*Nyctophilus* spp.)	medium frequency greatly varying over time	vertical linear shape	hunting in dense vegetation
E	along creek lines	moderate speed, moderate manoeuvreability	intermediate wing shape: eg. *Myotis*	similar to longeared less rapid and less frequent		water surface prey detection

Other researchers have classified bat species into “clutter tolerant” and “clutter intolerant” categories (Norberg and Rayner, 1987), or bats of, “uncluttered”, “background cluttered”, and “highly cluttered” spaces (Schnitzler and Kalko 1998). These classifications are a recognition that echolocation construction facilitates cluttered habitat foraging.

Thus ultrasound echolocation call characteristics have been linked in various ways to the ecological niches occupied by microbats.

Ultrasound as a basis for guild structure

Simmons and Stein (1980) provided the following eloquent description of echolocation used by microbts:

> “The biological sonar, or echolocation, of bats is a perceptual system in which sounds are emitted specifically to produce echoes from objects for gathering information about these objects. . . . Echolocation is an acoustic imaging system in which the bat’s auditory nervous system is the signal-processing component. Bats emit sounds in the range of 10 to over 150 kHz from the larynx and vocal tract, and they perceive the immediate environment as acoustic images assembled from information received in echoes at the two ears.”

Microbats utilise echolocation for many activities including navigation through different habitat structures, location and tracking a variety of prey, and communication incorporating sexual recognition (Kazial and Masters 2004, Siemers and Kerth 2005) and distress (Russ *et al*. 2004). These activities are facilitated by the ability to alter calls (Siemers and Schnitzler 2004, Bartonicka and Rehak 2005) as well as to learn habitat specific calls (Wund 2005).

Depending on the species, microbats employ a range of foraging strategies (Weinbeer and Kalko 2004) that include capture of insects on the wing (aerial) either during continuous flight or from perch hunting, and/or collection of food from surfaces (gleaning) from either vegetation or the ground (Fenton 1990, Schnitzler and Kalko 1998). Each of these strategies requires different uses of prey detection and capture capabilities, many of which are determined by morphological parameters such as wing length and shape and body size consequently affecting maneuverability. Maneuverability in turn determines echolocation structure and frequency.

Large fast flying bats require long-distance information, slower more maneuverable bats require more detailed information of closer objects. Low frequencies become less attenuated and travel longer distances, whereas higher frequencies (>20 kHz) travel across shorter distances due to lost energy through spreading and attenuation. To avoid interference of received echolocation, timing of wing beat and therefore wing size is of major importance (Holderied and von Helversen 2003). Very generally, faster flying species use lower frequencies and slower flying species use higher frequencies. Medium size, mid-range wing dimensions affording mid-range speed, maneuverability and associated echolocation characteristics, result in flight and foraging versatility and therefore access to a range of insect habitat and behaviour. Slow but highly maneuverable flight patterns facilitate access within vegetation.

Microbat calls are comprised of FM (frequency modulated) and/or CF (constant frequency) signals, which perform different functions depending on the combination and the species. Constant frequency (CF) signals inform microbats of velocity (distance, speed and direction of insect prey) by the Doppler effect shift in frequency (Simmons *et al.* 1975). Frequency modulation (FM) signals inform microbats of distance and size of an object but not speed and direction, by the return time of sound waves. Complexity in the calls provide details of texture and density of targets. Improvement of discriminating qualities is achieved for CF signals by extending the frequency bandwidth with harmonics, and for FM signals by introducing harmonics and increasing the rapidity of the pulses (Simmons & Stein 1980, de Oliveira 1998, and Churchill 1998).

Complexities in selecting parameters for establishing community structures

Two recent studies highlight the problems in selecting parameters for community structures.

In new research Seimers and Schnitzler (2004) found that difference in microbat prey capture success was not due to differences in wing morphology and therefore ability to sustain slow maneuverable flight, but mainly to differences in echolocation call parameters and related differences in echo-processing capabilities. A strong correlation was found between the prey-detection ability of species and their respective search-call bandwidth, which contributed to within-guild niche differentiation. Species with higher starting frequencies and bandwidths, and shorter pulse intervals were able to capture prey closer to clutter than those with lower starting frequencies and bandwidths and higher pulse intervals. It was argued there was therefore an association between broad bandwidth and good capture ability in cluttered environments, suggesting that bandwidth broadening could be achieved by increasing the starting frequency.

Additionally a recent study of a species-rich neotropical bat community (Weinbeer and Kalko 2004) linked echomorphological characters and resource use. A gleaning bat species usually associated with understorey vegetation and the ground, but with longer wings and smaller ears than other gleaning species, utilised upper canopy and open spaces as foraging areas. The study identified that fine-grained resource partitioning was based not only upon differences in size and use of foraging areas, but also on differences in activity patterns and foraging strategies. It concluded that all factors played key roles in structuring bat communities to facilitate long-term species co-existence.

6.6.2 FITTING A GUILD STRUCTURE TO THE STUDY AREA ASSEMBLAGE

Families and genera

The species identified in the study area were initially classified by family and genus within which the ultrasound frequencies varied extensively (Table 6.6d).

Table 6.6.d. Species arranged by family and genus
Ultrasound frequencies determined from NSW western slopes & plains (Pennay *et al.* 2004) & Spring 2003 harp trap survey

Species arranged in families and genera	Minimum ultrasound Freq. kHz	Maximim ultrasound Freq. kHz
Emballonuridae - sheathtail		
Saccolaimus flaviventris (yellow-bellied sheathtail)	17.5	22
Molossidae - freetail		
Mormopterus sp. 2 (eastern freetail)	28.5	31
Mormopterus sp. 3 (inland freetail)	34.5	35
Mormopterus sp. 4 (southern freetail)	26	29.5
unidentified calls	27	33
Tadarida australis (whitestriped freetail)	10	13
Vespertilionidae – evening **broadnosed**		
Scotorepens balstoni (inland broadnosed)	29	34
Scotorepens greyii (little broadnosed)	36.5	40
wattled & pied		
Chalinolobus gouldii (Gould’s wattled)	27.5	33
Chalinolobus morio (chocolate wattled)	48.5	51.5
Chalinolobus picatus (little pied)	42	44
forest		
Vespadelus darlingtoni (large forest	41	44
Vespadelus regulus (southern forest)	45	46
Vespadelus troughtoni (eastern cave)	48	55
Vespadelus vulturnus (little forest)	46	49
longeared		
Nyctophilus spp. (longeared)	40	71

Ultrasound and frequency range

As increasing volumes of research link ultrasound characteristics and frequencies to not only microbat wing length and wing beat, but also to insect size, microbat foraging habitat and foraging efficiency, and because a component of this study was to investigate relationships beetween microbat ultrasound frequencies and insect response, the microbat species identified were grouped according to ultrasound frequencies. Species were ordered from lowest to highest frequency (Table 6.6e). Grouping was determined by frequencies audible to hearing insects. This guild structure also captured some family differentiation.

The ultrasound frequencies used by the study area species ranged from 10 to 71+kHz. Guild 1 species utilised frequency ranges from 10 to 22kHz, Guild 2 from 26 to 35kHz, Guild 3 from 36.5 to 49kHz, and Guild species 4 from 48 to 71kHz. Frequency ranges were determined from release calls for species captured during the spring 2003 Harp trap survey, and from calls for NSW western slopes and plains (Pennay *et al*. (2004). Previous guild classifications are included in Columns 5, 6 and 7 (Table 6.6e).

Table 6.6.e. Species arranged in Guilds according to ultrasound frequency range and ranges of insect sound perception (NSW Western slopes and plains in Pennay *et al.* 2004, and 2003 spring harp trap survey)

Species arranged in Guilds lowest to highest ultrasound frequency	Characteristic Frequency kHz	CallSignal type	Cat. 1 O'N&T	Cat. 2 Herr	Cat. 3 de Oliveira
Guild 1					
Tadarida australis (whitestriped freetail bat) (Molossid)	10-13	(flat) FM		A	A
Saccolaimus flaviventris (yellow-bellied sheathtail) (Emballonid)	17.5-**22**	(flat/curved) FM		A	
Guild 2					
Mormopterus sp. 4 (southern freetail bat) (Molossid)	**26-29.5**	(flat) FM			A
Chalinolobus gouldii (Gould's wattled bat) (Vespertilionid)	**27.5-33**	(curved) FM	A	B	B
Unidendified calls	**27-33**	(flat/curved) FM			
Mormopterus sp. 2 (eastern freetail bat) (Molossid)	**28.5-31**	(flat) FM			A
Mormopterus sp. 3 (inland freetail bat) (Molossid)	**34.5-35**	(flat) FM			A
Scotorepens balstoni (inland broadnosed) (Vespertilionid)	**29-34**	(curved) FM			C
Guild 3					
Scotorepens greyii (little broadnosed bat) (Vespertilionid)	**36.5-40**	(curved) FM			C
Chalinolobus picatus (little pied bat) (Vespertilionid)	**42-44**	(curved) FM			
Vespadelus darlingtoni (large forest bat) (Vespertilionid)	**41-44**	(curved) FM	B	C	
Vespadelus regulus (southern forest bat) (Vespertilionid)	**45-46**	(curved) FM	C	C	
Vespadelus vulturnus (little forest bat) (Vespertilionid)	**46-49**	(curved) FM	C	C	
Guild 4					
Chalinolobus morio (chocolate wattled bat) (Vespertilionid)	**48.5**-51.5	(curved) FM	B	C	
Vespadelus troughtoni (eastern cave bat) (Vespertilionid)	**48**-55	(curved) FM			
Nyctophilus gouldi (Gould's longeared bat) (Vespertilionid)	**40**-67	(linear) FM	D	D	D
Nyctophilus timoriensis (greater longeared bat) (Vespertilionid)	**43**-71	(linear) FM	D	D	D
Nyctophilus geoffroyi (lesser longeared bat) (Vespertilionid)	**46**-66	(linear) FM	D	D	D

KEY

Bolded	Characteristic Frequency ranges (kHz) within insect sound perception (Note: Characteristic frequency, used for identification,is the flattest component of a more extensive call)
Category 1	O'Neil and Taylor 1986 (Chapter 4.7. Methodology)
Category 2	Herr 1998 (Chapter 4.7. Methodology)
Category 3	de Oliveira 1998 (Chapter 4.7. Methodology)

Ultrasound frequency and insect sensitivity

Insects are most sensitive to ultrasound frequencies >20 kHz and <50 kHz (Pavey and Burwell 1998). A very defined drop-off in insect sound perception occurs above 60 kHz (Fullard 1987, Bogdanowicz *et al.* 1999). As Guilds 2 and 3 species use ultrasound frequencies between 20 and 50kHz these guilds represent microbat species using echolocation to which insect species are attuned (Table 6.6e).

Outside the range of insect sensitivity are the frequencies utilised by *Tadarida australis*, and the minimum frequencies utilised by *Saccolaimus flaviventris*, both in Guild 1. Most of the call components, ie. frequencies above 50 kHz, utilised by the three "whispering bats" *Nyctophilus* spp. and the highest frequencies utilised by the two other Guild 4 species, *Chalinolobus morio* and *Vespadelus troughtoni*, are also outside the audible range of many insects. It has been suggested (Grant 1991) that one of the reasons that *Nyctophilus* spp. often forage using sight and hearing rather than echolocation is to circumvent the evasive response of sonar-sensitive insects.

Microbat species using frequencies <20 and >100 kHz have been shown to include higher proportions of eared moths and, in some cases, beetles in their diet. Jaw structure and strength are also contributing factors dietary difference (Bogdanowicz *et al.* 1999). Many species using frequencies >20 and <50kHz, together with a range of foraging strategies, have however been shown to include eared moths in their diet (Fullard 1987).

Ultrasound and signal type

Echolocation signal type is an important characteristic determining foraging pattern and strategy (6.6.1). True CF (Constant Frequency) bats are the Rhinoplophids and Hipposiderids, all others are considered to have FM (Frequency Modulated) or FM/CF calls. All the species in the study area use calls that change in frequency (i.e. start higher and drop to a lower frequency no matter how small) defined as FM calls. Most have a CF component at the end of the call where the call flattens out, but are still called FM calls. However Molossid calls could be called "flat", *Nyctophilus* calls called "linear" and the remainder of species in the study area called "curved".

Both Guild 1 species utilise low flat FM signals and characteristic frequencies from 10 to 13kHz for *T. australis*, and from 17.5 to 22kHz for *S. flaviventris*.

All five Guild 2 species utilise flat FM or curved FM signals. The Molossids (*Mormopterus* spp.) use characteristic frequencies between 26 to 36kHz, the two Vespertilionids use characteristic frequencies between 27.5 and 34 kHz), *S. balstoni* (29-34) and *C. gouldii* (27.5-33).

All five Guild 3 species utilise curved FM signals and characteristic frequencies between 36.5 and 49 kHz - *S. greyii* (36.5-40), *V. vulturnus* (36.5-49), *V. darlingtoni* (41-44), *C. picatus* (42-44) and *V. regulus* (45-46)

All five Guild 4 Vespertilionid species utilise curved or linear FM signals, and characteristic frequencies between 48–75kHz) - *V. troughtoni* (48-51), *C. morio* (48.5-51.5), and the three *Nyctophilus* species utilise linear FM broadband signals (40-75).

Forearm length and body weight

Forearm length and body weight are standard measurements used in the identification of microbat species and assessment of possible flight patterns. For the species identified in the study area, the minima and maxima forearm lengths and body weights (Churchill 1998) were charted against the proposed guild structure (Fig 6.6a).

The forearm length variables for the species in the study area differ from 26.2. to 82.1mm. The species with the longest forearm parameters, from longest are, *S. flaviventris* (65.7-82.1mm) and *T. australis* (59.5-62.5mm) both in Guild 1, *N. timoriensis* (39-50mm) and *N. gouldi* (36.3-41.8mm) both in Guild 4, *C. gouldii* (36.6-45.9mm) in Guild 2, and *S. balstoni* (32-40.5mm) in Guild 3. The species with the shortest forearm parameters are *V. vulturnus* (26.2-32.8mm) in Guild 3, *Mormopterus* sp. 2 (30.6-34.2mm) in Guild 2, and *V. regulus* (28.-34.4mm) and *S. greyii* (27.3-35mm) in Guild 3.

Guild 1 comprises the two species with the longest forearm parameters, Guild 2 includes two longer, two medium and one short forearm parameter species, Guild 3 includes three short and two medium forearm parameter species, and Guild 4 includes three longer and two medium forearm species.

The species with the heaviest body weight parameters were *S. flaviventris* (30 to 60g), *T. australis* (33 to 44g), *N. timoriensis* max. (11 to 20g), *C. gouldii* (10 to 20g) and *N. gouldi* (9 to 16.5g). The species with lightest body weight parameters were *V. vulturnus* (3 to 6.8g), *V. regulus* (3.6 to 7.8g), *V. troughtoni* (4 to 6.7g), *S. greyii* (4 to 11g, *C. picatus* (4.3 - 7.1g), *N. geoffroyi* (4.6g but to a maximum of 14.5g), and *C. morio* (5.5 to 10.3g).

Guild 1 comprises species with the heaviest body weights, compared to the Guild 3 species with generally the lightest body weights. Guilds 4 and 2 are comprised of species with a variation in body weight.

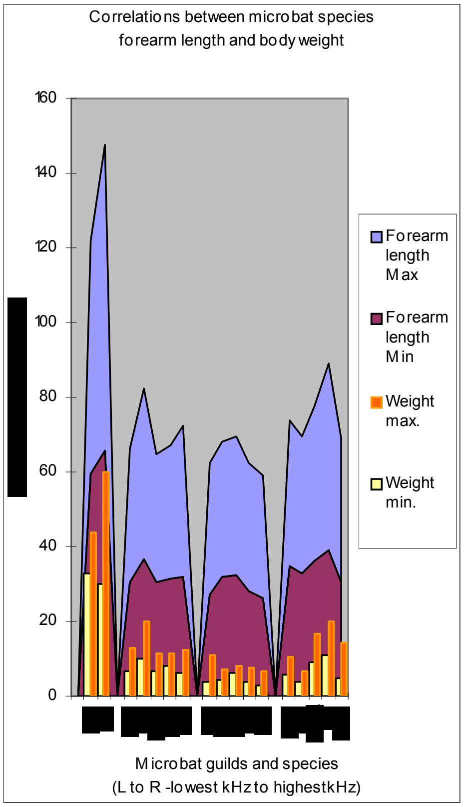


Fig. 6.6.a. Relationships between Guilds of microbat species based on ultrasound frequencies, and forearm length and body weight

KEY

Guild 1: (*T.a.*) *Tadarida australis*
(*S.f.*) *Saccolaimus flaviventris*
Guild 2: (*M*.4) *Mormopterus* sp. 4
(*C. g.*) *Chalinolobus gouldii*
(*M.* 2) *Mormopterus* sp. 2
(*M*.3) *Mormopterus* sp. 3
(*S.b.*) *Scotorepens balstoni*
Guild 3: (*S.g.*) *Scotorepens greyii*
(*C.p.*) *Chalinolobus picatus*
(*V.d.*) *Vespadelus darlingtoni*
(*V.r.*) *Vespadelus regulus*
(*V.v.*) *Vespadelus vulturnus*;
Guild 4: (*C.m.*) *Chalinolobus morio*;
(*V.t.*) *Vespadelus troughtoni*
(*N.go.*) *Nyctophilus gouldii*
(*N t.*) *Nyctophilus timoriensis*
(*N.ge.*) *Nyctophilus geoffroyi*

Forearm length, body weight and ultrasound frequencies

Species with the longest forearm length and heavier body weights, *T. australis* and *S. flaviventris* in Guild 1, also utilise the lowest frequency ranges (Fig. 6.6a). These two species fly very fast and are known to forage in open spaces. A relationship is also shown between long forearm length and higher body weights for three Guild 4 species (*N. timoriensis*, *N. gouldi*, and *C. morio*), however these species utilise the highest ultrasound frequencies and are known to forage within vegetation, suggesting other influencing factors.

Longer forearm length is related to higher body weight for species *C. gouldii* but less obviously for *S. balstoni* in Guild 2, *S. greyii* in Guild 3, or *N. geoffroyi* in Guild 4. Minimum and maximum body weight variations could account for differences for the last two species. Both *C. gouldii* and *S. balstoni* in Guild 2 utilise lower frequencies, whereas *S. greyii* in Guild 3 and *N. geoffroyi* in Guild 4 utilise higher frequencies.

Very generally long forearm lengths can be related to fast flight, lack of maneuverability and probable use of lower frequencies, or, with overall body size. Shorter forearm length can be related to fast flight if the bat is small in overall size and the wing is narrow, however if shorter forearm length is combined with broader wings, flight speed is reduced and maneuverability increased.

6.6.3 COMBINING PARAMETERS FOR GUILD STRUCTURE

No single parameter provides a clear indication of expected foraging pattern, however the combinations of ultrasound frequency, forearm length and body weight provide a partial picture. With the addition of a wing width parameter affording an estimate of flight speed and maneuverability, a clearer understanding of foraging patterns emerge.

Table 6.6f (Attachment 6.6) sets out the array of parameters for each species within the study area microbat assemblage. Guilds of species based predominantly on ultrasound frequency range and call signal categories are set out in columns 1 and 2 respectively. The variations in call structure facilitating increased information on foraging habitat are included in column 3. Assemblage ratings allocated for forearm length and minimum and maximum body weight are included in columns 4 and 5 respectively. Other parameters included are wing width categorised as narrow or broad (column 6), flight speed, high, medium or low (column 7), a maneuverability rating of low, medium, high or extreme (column 8), and known foraging areas (column 9). Whilst many microbat species are opportunistic predators the known prey type from various Australian studies are set out in column 10. Information was collated from sources notated within Table 6.6f (Attachment 6.6).

Guilds using frequencies outside insect sensitivity

Guild 1

A set of diagrams, Table 6.6g in Attachment 6.6, illustrate the foraging patterns for each species within the study area guild structure. Prey preferences described below have been collated from Churchill (1998).

Both Guild 1 species utilise the lowest frequencies and either flat or curved FM signals, increase ultrasound characteristic frequencies with harmonics, are the largest bats with the longest forearm measurements, have narrow wings, and fly at speed with low maneuverability. Differences occur however in foraging patterns and prey type. *T. australis* forages well above the canopy and on the ground and is known to feed predominantly on moths, but also on beetles, bugs, ants and grasshoppers as well as non-flying beetles, the latter a reflection of ground foraging activities. S*accolaimus flaviventris* in comparison, forages above the canopy, and is known to feed predominantly upon beetles as well as bugs, ants and grasshoppers, though not on moths or non-flying beetles.

Guild 4

Guild 4 species that utilise the highest frequencies differ in more than foraging patterns and prey species. Three species use broadband FM signals, two being large bats with long but broad wings (*N. timoriensis*, *N. gouldi*). The third, *N. geoffroyi*, has broad but not long wings and wide variation in minimum and maximum body weight. All three species have slow flight patterns, are extremely maneuverable, utilise passive listening and sight to supplement echolocation not used for navigation, and glean from vegetation and the ground as well as capture prey in flight. However their foraging patterns and prey selection differ.

N. timoriensis, the largest species, is known to forage from the understorey to the ground opportunistically predating upon non-flying organisms that include predominantly caterpillars, as well as scorpions and moths. *N. gouldi* forages below the canopy, among trees, and within vegetation, capturing prey in flight or gleaning from vegetation as well as on the ground, and is an opportunist, but known to predate predominantly upon moths, as well as beetles, bugs, spiders, flies and ants. *N. geoffroyi*, foraging in gaps between the canopy and the understorey, within the understorey and upon the ground, is alsoan opportunist. This species in however known to also predate primarily upon moths as well as beetles, bugs and spiders as prey, but additionally lacewings, crickets, non-flying ants and cricket nymps, captured in flight as well as gleaned from vegetation and the ground.

The other two Guild 4 species are small bats that utilise curved FM signals either with some alternation or variation. Little is known of the foraging behaviour of *V. troughtoni*. *C. morio*, in contrast to the *Nyctophilus* species, has long wings, flies at medium to high speed, with medium to high maneuverability, but nevertheless forages in some of the same areas - the gaps between the canopy and the understorey. *C. morio* is known as an opportunist but predates upon only flying prey, the prey selection showing some similarities to that predated upon by *N. gouldi* and *N. geoffroyi*. These three species prey predominantly upon moths, beetles, bugs and flies, *C. morio* and *N. gouldi* on ants, and *C. morio* and *N. geoffroyi* on lacewings. *C. morio* is however known to also predate upon wasps as well as termites.

Guilds using frequencies within insect sensitivity

Guild 2

Guild 2 species are generally larger than Guild 3 species. Three of the Guild 2 species, use flat FM signals supplemented by a variation in call characteristics from harmonics to curved modulation, have very similar forearm length, are medium sized bats, have narrow wings, high flight speeds and low maneuverability, however their foraging patterns vary. Whilst *Mormopterus* sp. 4 forages above the canopy, between trees, along edges of remnants and on the ground, *Mormopterus* sp. 3 forages in open spaces, and the foraging patterns are unknown for *Mormopterus* sp. 2. *Mormopterus* sp. 4 predates upon bugs many of which are agricultural pests, as well as beetles, ants, moths and ground organisms, *Mormopterus* sp. 3 predates upon at least flies and ants, and *Mormopterus* sp. 2 is known to predate upon bugs, ants and beetles.

The other two Guild 2 species (*C. gouldii* and *S. balstoni*) are very different. *C. gouldii* use very similar frequencies to the *Mormopterus* species but utilises curved FM signals, is a large bat with narrow wings, has a medium to high flight speed but a medium to low maneuverability. *C. gouldii* similarly forages along the edges of remnants but also within the lower canopy and within canopy gaps. An opportunist, *C. gouldii* however also predates upon bugs, beetles, and flies but in contrast to the *Mormopterus* species, predates predominantly upon moths and also on crickets.

S. balstoni, although using the highest frequency of the Guild 2 species, uses curved FM signals supplemented with a variation of frequencies over time. Like the *Mormopterus* species, *S. balstoni* is a medium sized bat, but has long broad wings, and therefore a medium flight speed and is the only Guild 2 species with high maneuverability. Though also foraging along edges of remnants *S. balstoni* includes, amongst trees from 15m., to the ground, and open spaces, as foraging areas. This species also predates upon beetles, bugs, moths, flies, and crickets, but in addition includes ants, grasshoppers, cockroaches and non-flying insects as prey.

Guild 3

Apart from using similar frequencies, species within Guild 3 are similar in their small to medium size, their medium to high flight speed and their medium to high maneuverability. The differences are, the medium flight speed and high maneuverability of *S. greyii*, and only medium maneuverability for *C. picatus*. Differences do however occur with the extension of curved FM call signals, supplemented by frequency variations over time by *S. greyii* and *V. vulturnus*, compared to modulation (*V. darlingtoni*), and alternation by *C. picatus*.

The foraging areas and prey are unknown for *C. picatus* and although the foraging areas are also unknown for *S. greyii*, its high level of maneuverability and known prey including non flying ants and termites suggest that the ground is included in its foraging habitat. This species is known as an opportunistic predator, and includes crickets, leaf hoppers, bugs, beetles, flies and moths as prey.

The foraging areas as well as prey selection vary for the three Vespertilionid Guild 3 species. Whilst *V. vulturnus* forages at the highest level below the canopy, *V. darlingtoni* forages in the gaps between the canopy and the understorey and *V. regulus* forages in less than half the canopy height. *V. darlingtoni* forages among trees whilst *V. vulturnus* between trees, *V. vulturnus* forages within the understorey 3-8 metres from the ground whilst *V. regulus* forages in the understorey, within vegetation, as well as on the ground. The prey selection for each species varies accordingly.

Although *V. regulus* and *V. vulturnus* are both opportunistic predators they use different foraging strategies. *V. vulturnus* although flying close to vegetation takes only flying insects and does not glean from the vegetation, and *V. regulus* includes ground organisms as dietary components. All three species are known to predate predominantly upon moths, but also include beetles, bugs, flies and ants as prey, and whereas *V. darlingtoni* and *V. vulturnus* both also prey on spiders, termites and lacewings, *V. vulturnus* includes grasshoppers, wasps and cockroaches as prey species.

6.6.4 CONCLUSION

As a means of initially assessing the suitability of the selected guild structure for this study, Fig. 6.6c combines guilds based that are based on both ultrasound frequencies used by individual microbat species and frequencies heard by insects, and the seasonal presence at sites for individual species. Although it is recognized there are differences in call detectability, such as the softness of *Nyctophillus* spp calls, it would appear that the guilds based predominantly on ultrasound frequencies and frequencies heard by insects, reflect much of the microbat species differentiation in the study area.

A summary of the other parameters pertaining to the Guild structure based on ultrasound frequencies is included in Fig. 6.6d. Although the species within each guild use similar ultrasound frequencies, the variations in all other parameters would appear to enable differentiation of prey species and therefore niche differentiation for microbat species within each guild.

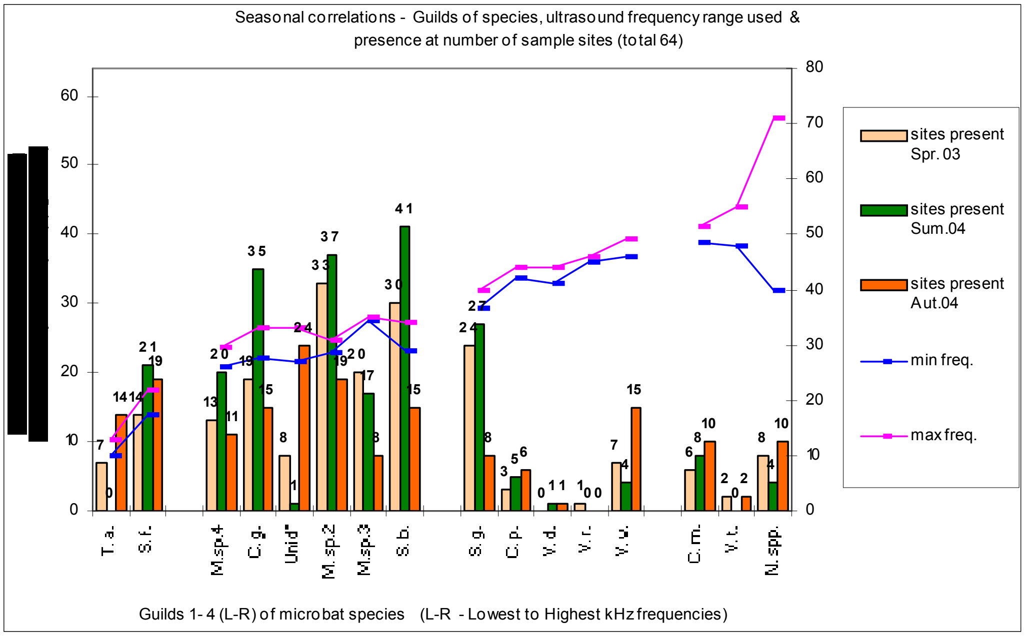


Fig. 6.6.b. Relationships between Guilds of species, their associated ultrasound Characteristic Frequency ranges, and seasonal presence at number of sample sites (SSA03/04 surveys) (Species identification and frequency ranges - Pennay *et al*. 2004, Law *et al.* 2002 and Spring 2003 Harp trap survey release calls)

SPECIES KEY:

Guild 1: (*T.a.*) *Tadarida australis*; (*S. f.*) *Saccolaimus flaviventris*;

Guild 2: (*M.* sp. 4) *Mormopterus* sp. 4; (*C. g.*) *Chalinolobus gouldii*; (*M.* sp.2) *Mormopterus* sp. 2; (*M.* sp.3) *Mormopterus* sp. 3; (*S. b.*) *Scotorepens balstoni*;

Guild 3: (*S. g.*) *Scotorepens greyii*; (*C.p.*) *Chalinolobus picatus*; (*V. d.*) *Vespadelus darlingtoni*; (*V. r.*) *Vespadelus regulus*; (*V. v.*) *Vespadelus vulturnus*;

Guild 4: (*C. m.*) *Chalinolobus morio*; (*V. t.*) *Vespadelus troughtoni*; (*Ny.* spp.) *Nyctophilus* spp.

Microbats

Guild 1	Guild 2	Guild 3	Guild 4
Low ultrasound Characteristic Frequency ranges	Medium ultrasound Characteristic Frequency ranges	Medium/high ultrasound Characteristic Frequency ranges	High ultrasound Characteristic r Fequency ranges
outside insect audible range	within insect audible range	within insect audible range	outside insect audible range
high fliers fast flight patterns	medium speed medium maneuverability	very maneuverable flight patterns	very maneuverable flight patterns
open space foraging	edge and gap foraging	understorey dependent foraging	within vegetation foraging

Fig. 6.6.c. The principal parameters of differentiation between Guilds based predominantly on ultrasound frequencies for the study area.

Table 6.6.f. Guilds of species based on ultrasound frequency range, and associated morphological parameters and consequential behavioral characteristics.

Guilds of species based on ultrasound kHz (lowest G1 to highest G4)	Call Signal (flat/ curved/ linear) FM (ll)	Freq. & Call signal extension (ch, p, SSA) (Although all bats use harmonics some harmonics are recorded more easily by Anabat)	Fa. Length (ch) assemb. rating (1=long 17=short)	Weight (ch) assemb. rating: min (smallest 1-17); max (largest 1-17)	Wing width (do) Narrow Broad	Flight speed High Med Low	Maneuverability Low, Medium, High, Extreme	Foraging areas (ch, h)	Prey type (ch)
Guild 1									
T. australis	fFM	harmonics	2	17 - 2	N	H do	L do	wac,gr	pm,be,bu,a, gh,nfbe.
S. flaviventris	f/c FM	harmonics	1	16 - 1		H do *	L do*	ac	pbe,bu,a,gh
Guild 2									
Mormop. sp. 4	fFM	harmonics	13	10 - 7	N	H * h	L * h	bt,e,ac,gr	pbu*be,a,m
Unidendent.	f/cFM	descending	*						
C. gouldii	cFM	CF	4	14 - 4	N	H do M/H h	M do M/L h	wic,cg,e	opp,pm,bu,be,f,cr,c,a,st,ci,lh
Mormop.sp. 2	fFM	occas modulation	16	10 - 9	N				bu,a,be,m.
Mormop.sp. 3	fFM	modulation	12	12 - 9	N	H * h	L * h	os	* f,a
S. balstoni	cFM	varying over time	6	9 - 8	B	M do	H do	at/e/os/<15m/gr	opp,be,a,bu,m,f,gh,co,cr,ci, nf
Guild 3									
S. greyii	cFM	varying over time	14	3 - 11	B	M do	H do		opp,nfa,t.cr,lh,bu,be,f,m
C. picatus	cFM	alternating	11	5 - 15		M/H ot	M ot		? m
V.darlingtoni	cFM	somemodulation	9	8 - 13		M/H h	M/H h	at,gbc&u	pm,be,f,bu,s,t,a,lw
V. regulus	cFM		15	2 - 14		M/H h	M/H h H ch	wic,wu,wv,gr	opp,pm,be,f, bu,a
V.vulturnus	cFM	varying over time	17	1 - 16		M/H h	M/H h	wu,bt,bc,3-8m	opp,fp,pm,f,bu,be,t,s,gh,lw,a,w,co
Guild 4									
C. morio	cFM	alternation	6	7 - 12		M/H h	M/H h	gbc&u,ft	opp,pm,be,bu,f,a,lw,w,t
V. troughtoni	cFM	varying	10	3 - 17				*	*
N. gouldi	lFM	broadband	5	12 - 5	B	L do, h	E do, h	wv,at,bc,gr GL	pm,opp,be,bu,s,f,a
N. timoriensis	lFM	broadband	3	15 - 3	B	L do	E do	utg,gr GL	nf,opp,pc,sc,m
N. geoffroyi	lFM	broadband	8	6 - 6	B	L do, h	E do, h	utg,gbc&u,gr GL	pm,opp,s,nfa,be,cr,bu,lw,f,cr/nymphs

KEY

* unknown

References: (ot) O'Neill & Taylor (1986); (ch) Churchill 1998; (h) Herr 1998; (do) de Oliveira1998; (p) Pennay *et al*. 2004; (SSA) SSA03/04 surveys; (ll) Lindy Lumsden (pers. comm. 2008)

Species:

Guild 1: (*T. australis*) *Tadarida australis*; (*S. flaviventris*) *Saccolaimus flaviventris*;

Guild 2: (*Mormop*. sp. 4) *Mormopterus* sp. 4; (*C. gouldii*) *Chalinolobus gouldii*; (*Mormop*. sp. 2) *Mormopterus* sp. 2; (*Mormop*. sp. 3) *Mormopterus* sp. 3; (*S. balstoni*.) *Scotorepens balstoni*;

Guild 3: (*S. greyii*) *Scotorepens greyii*; (*C. picatus*) *Chalinolobus picatus*; (*V. darlingtoni*) *Vespadelus darlingtoni*; (*V. regulus*) *Vespadelus regulus*; (*V. vulturnus*) *Vespadelus vulturnus*;

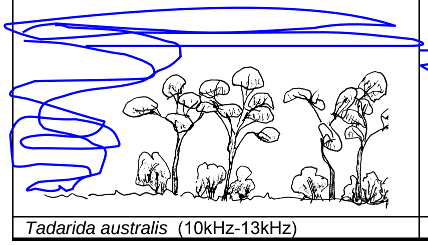
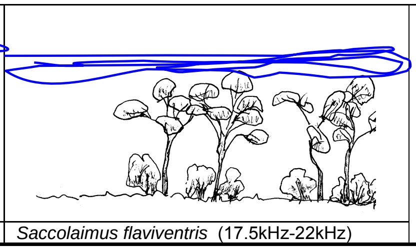
Guild 4: (*C. morio*) *Chalinolobus morio*; (*V. troughtoni*) *Vespadelus troughtoni*; (*N. gouldi*) *Nyctophilus gouldii*; (*N. timoriensis*) *Nyctophilus timoriensis*; (*N. geoffroyi*) *Nyctophilus geoffroyi*.

Foraging area: (ac) above canopy; (at) among trees; (bc) below canopy; (bt) between trees; (cg) canopy gaps; (e) edges; (ft) forest trails; (gbc&u) gaps between canopy & understorey; (gr) ground; (os) open spaces; (utg) understorey to ground; (wac) well above canopy; (wlc) within lower canopy; (wu) within understorey; (wuc) within upper canopy; (wv) within vegetation; .

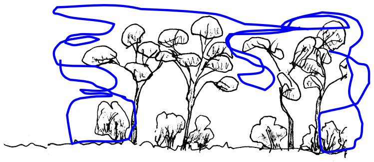
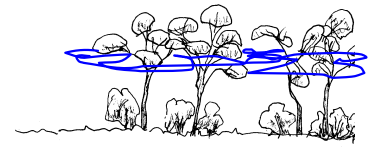
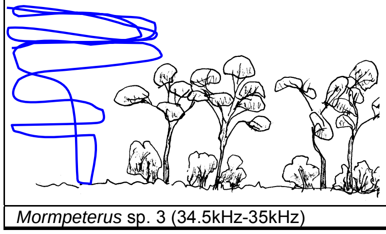
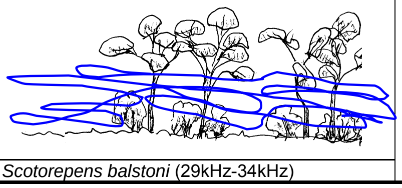
Prey: (a) ants; (be) beetles; (bu) bugs; (c) caterpillars;(ci) cicaders; (co) cockroaches; (cr) crickets; (f) flies; (fp) flying prey only; (gh) grasshoppers; (lh) leaf hoppers; (lw) lacewings; (m) moths; (nf) non flying; (opp) opportunist; (p) predominantly; (s) spiders; (sc) scorpions; (st) stoneflies; (t) termites; (w) wasps; * agricultural pests;

Table 6.6.g. Guilds of species based on ultrasound echolocation frequencies together with known, foraging patterns, prey, and roost preferences. (Churchill 1998, Pennay *et al.* 2004, Harp Trap survey Spring 2003)

GUILD 1 – lowest frequencies 10kHz-20kHz; flat FM +harmonics. **Outside insect sensitivity.**
large long wings, fast flying, low maneuverability.
Foraging: open space; *T. aust*. - well above canopy & ground; *S. flav*. above canopy
Known roost preference: Tree hollows

		**Known prey:** *Tadarida australis*: **pm**,be,bu,a,gh,**nfbe** *Saccolaimus flaviventris*: pbe,bu,a,gh
Tadarida australis (10kHz-13kHz)	*Saccolaimus flaviventris* (17.5kHz-22kHz)	

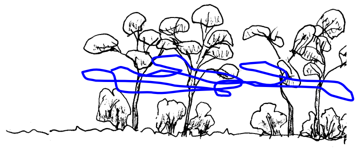
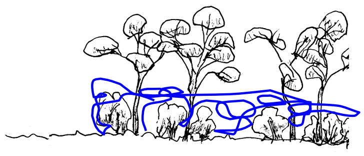
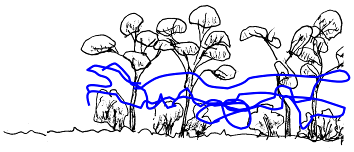
GUILD 2 – 26kHz - 35kHz; four species flat FM, two curved FM, variations over time. **Within insect sensitivity.**
mid-sized narrow wings, high-medium flight speed, low-medium maneuverability (except *S. bal*. high man.).
Foraging: all edge, open space or above canopy + Other foraging:*C. goul.* within canopy or canopy gaps; *M.* sp. 4 amongst trees; *S. bal*. between trees; *M.* sp. 4 & *S. bal.* ground.
Known roost preference: All tree hollows; *C. gouldii* river red gum dead limbs; *M*. spp. 2 tree spouts; *M*. sp. 4 narrow entrances; Others: *S. bal*., *M*. sp. 3 & 4 + roof cavities; *M*. sp. 3 + water pipes & often with *S. bal*.

		
Mormopterus sp. 4 (26kHz-29.5kHz)	*Chalinolobus gouldii* (27.5kHz-33kHz)	*Mormopterus* sp. 2 (28.5kHz-31kHz) **?**
		**Known prey:** *Mormopterus* sp. 4**: pbu***,be,a,m *Chalinolobusd gouldii*: opp,pm,bu,be,f,**cr**,**c**,a, **st**,**ci**,**lh** *Mormopterus* sp. 2: bu,a,be,m. *Mormopterus* sp. 3: ? f,a *Scotorepens balstoni*: opp,be,a,bu,m,f,**gh**,**co**, **cr**,**ci**, **nf**
Mormpeterus sp. 3 (34.5kHz-35kHz)	*Scotorepens balstoni* (29kHz-34kHz)	

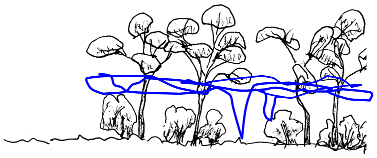
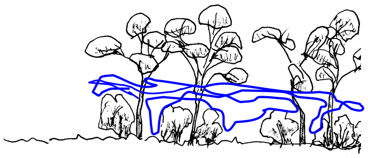
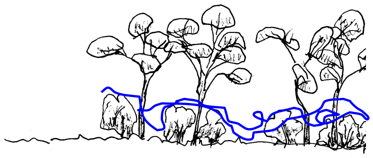
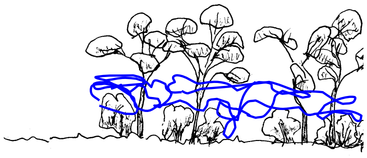
Known Prey: (a) ants; (be) beetles; (bu) bugs; (c) caterpillars;(ci) cicaders; (co) cockroaches; (cr) crickets; (f) flies; (fp) flying prey only; (gh) grasshoppers; (lh) leaf hoppers; (lw) lacewings; (m) moths; (nf) non flying; (opp) opportunist; (p) predominantly; (s) spiders; (sc) scorpions; (st) stoneflies; (t) termites; (w) wasps; * agricultural pests; **bolded**: prey not common to other species within Guild.

Table 6.6.g. Guilds of species based on ultrasound echolocation frequencies together with known, foraging patterns, prey, and roost preferences. (Churchill 1998, Pennay *et al.* 2004, Harp Trap survey Spring 2003)

GUILD 3 – 36kHz-49kHz; All curved FM; *S.grey*. *V.dar*.&*V.reg*. variation/time; *C. pic*.&*V.vul*. variation/ time/ alternate. **Within insect sensitivity**. small-sized broad wings?; medium to high fligh speed; medium-high maneuverability (except *S.grey*. med. speed/high man.).
Foraging: all below canopy, no open space; *V.vul*. below canopy+between trees, *V.darl*. gaps between can. and understorey+among trees, *V.reg*. less than half canopy height; Other foraging: *V. vul*. within understorey 3-8m. from ground, *V. reg*. understorey, within vegetation and ground.
Known roost preference: All tree hollows + buildings; Others: *C. morio* +bark, culverts, bridges; *C. picatus* +caves, mines; *S. grey*. + fence posts.

		
Scotorepens greyii (36.5kHz-40kHz) **?**	*Chalinolobus picatus* (42kHz-44kHz) **?**	*Vespadelus darlingtoni* (41kHz-44kHz)
		**Known prey:** *Scotorepens greyii*: opp,**nfa**,t.**cr**,**lh**,bu,be,f,m *Chalinolobus picatus*: ? m *Vespadelus darlingtoni*: pm,be,f,bu,s,t,a,**lw** *Vespadelus regulus*: opp,pm,be,f,bu,a *Vespadelus vulturnus*: opp,**fp**,pm,f,bu,be,t,**s**, **gh**,**lw**,a,**w**,**co**
Vespadelus regulus (45kHz-46kHz)	*Vespadelus vulturnus* (46kHz-49kHz)	

GUILD 4 –- highest frequencies predom. above 50kHz; *C. morio* & *V.trou*. curved FM +variation; *N*. spp. FM broadband+ passive listening & sight. **Predominantly outside insect sensitivity.**
Small-large sized, longer to short wing length, broad wings, low flight speed, extreme maneuverability (except. *C. morio* med/high speed & man.).
Foraging: all below canopy & no open space. *C. morio* gaps between canopy & understorey and along forest trails; , *N. geof*. gaps between canopy & understorey, *N. goul*. below canopy, among trees & within vegetation & understorey; *N. tim*. understorey to ground; all *N*. spp. glean from vegetation and ground;
Known roost preference: *C. morio* tree hollows, houses, bark, Fairy Martin nests, culverts, bridges; *V. troug*. caves, boulder piles, mines, buildings; *N. goul*. tree hollows, bark; *N. tim*. tree hollows, fissures in dead limbs/trees, bark; *N. geof*. fissures in dead trees, bark, buildings;

		
Chalinolobus morio (48.5kHz-51.5khz)	*Vespadelus troughtoni* (48kHz-55kHz) *?*	*Nyctophilus gouldi* (40kHz-67kHz)
		**Known prey:** *Chalinolobus morio*: opp,pm,be,bu,f,a,**lw**,**w**,**t** *Vespadelus troughtoni*: ? *Nyctophilus gouldi*: pm,opp,be,bu,**s**,f,a *Nyctophilus timoriensis*: **nf**,opp,**pc**,**sc**,m *Nyctophilus geoffroyi*: pm,opp,**s**,**nfa**, be,**cr**,bu,**lw**, f,**cr/nymphs**
Nyctophilus timoriensis (43kHz-71kHz)	*Nyctophilus geoffroyi* (46kHz-66kHz)	

Known Prey: (a) ants; (be) beetles; (bu) bugs; (c) caterpillars;(ci) cicaders; (co) cockroaches; (cr) crickets; (f) flies; (fp) flying prey only; (gh) grasshoppers; (lh) leaf hoppers; (lw) lacewings; (m) moths; (nf) non flying; (opp) opportunist; (p) predominantly; (s) spiders; (sc) scorpions; (st) stoneflies; (t) termites; (w) wasps; * agricultural pests; **bolded**: prey not common to other species within Guild.

CHAPTER 6.7 MICROBATS AND VEGETATION ACROSS THE LANDSCAPE

Contents:

INTRODUCTION

If there is a microbat presence across a cotton production landscape how does the presence manifest? The examination of seasonal spatial landscape distribution of the microbat community in this chapter is divided into two sections. Call abundance distribution is the focus of the first section, and species and guild distribution the second focus. Both sections will initially examine how the distribution of microbats is related to the natural vegetation occurring in the study area. Next, both sections will explore how microbats utilise anthropogenic features of the landscape related to agricultural production particularly cotton (fields and water storages). Finally both sections will match spatial and temporal variation of microbat calls within and between natural and cotton related landscape features.

Throughout this chapter abbreviations are used for the ten landscape categories (A) to (J) in graphs and tables, and (rgf) to (dc), or a combination of both in the text. The abbreviations, the landscape categories and in brackets their sample effort, are listed below. Wherever seasonal comparisons occur the seasonal order used is spring, summer and autumn unless otherwise specified.

Native vegetation categories:
A or rgf- river gum forest (5)
B or rgow – river gum open woodland (11)
C or pb – poplar box (7)
D or gb – grey box (2)
E or mix – mixed species (6)
F or cp - cypress pine (4)
G or git – grasslands & isolated trees (4)

Intensive management categories:
H or ic – irrigated cropping (16)
I or ws – water storage (4)
J or dc – dryland cropping (5)

PART A CALL ABUNDANCE DISTRIBUTION – SEASONAL COMPARISON

6.7.1 BATS IN THE NATURAL LANDSCAPE

Seasonal distribution

If all habitats were of equal value for microbats, the same distribution of both call and feeding buzz abundance would be repeated across vegetation types and across seasons. This section compares the results for native vegetation landscape categories, across three seasons. For each native vegetation category a seasonal comparison of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca) is set out in Fig. 6.7a. The sample effort representing the percentage of the study area landscape for each native vegetation category, is replicated for each season.

Microbat total call abundance (mtca)

There was little seasonal variation in microbat total call abundance. Total call abundance in spring (473) was only 11% higher than in summer (425) and 12% higher than in autumn (417). Nevertheless the distribution pattern of total call abundance across the native vegetation landscape categories showed seasonal shifts between categories.

The most evenly distributed total call abundance was in summer, with abundance spread in decending order across categories Brgow, Cpb, Emix, Fcp and Argf. Call abundance in spring was however more concentrated with activity peaks in decending order, across categories Argf, Cpb and Emix, with a reduced abundance for Brgow. By comparison the generally lower autumn abundance was concentrated in Brgow. Seasonal shifts for lowest total call abundance moved from Fcp in spring to Dgb in summer and Ggit in autumn.

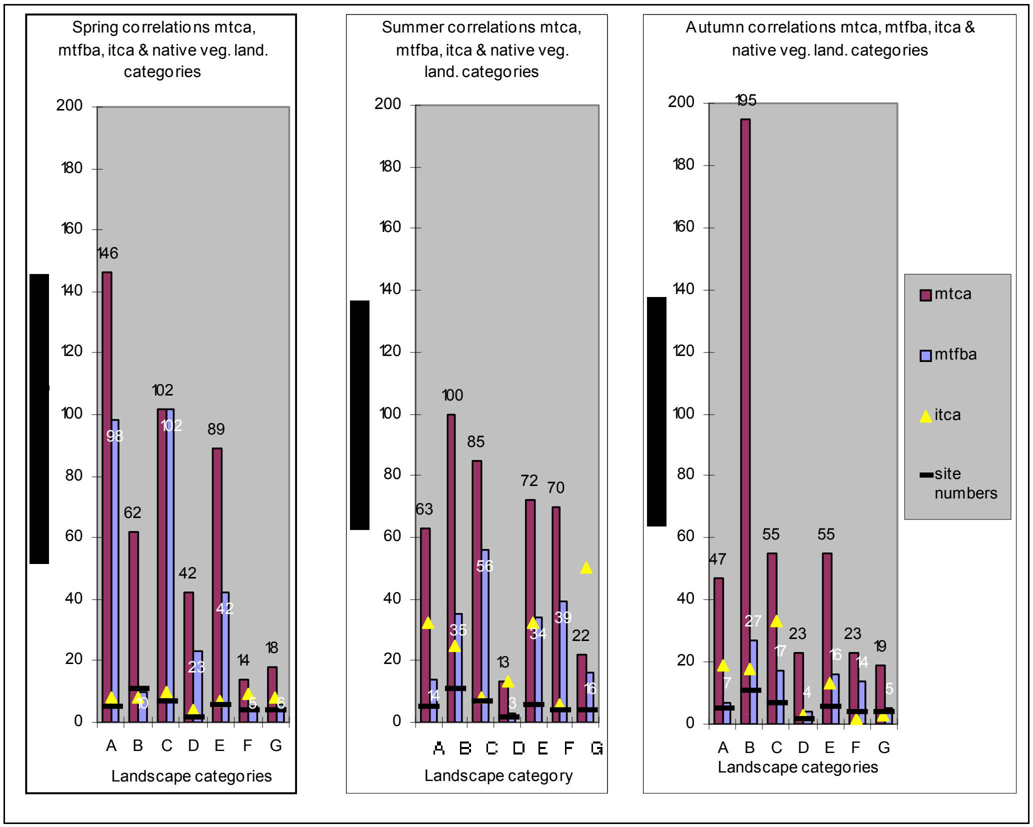


Fig. 6.7.a. Seasonal comparisons of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca) for native vegetation landscape categories. (SSA03/04 surveys)
KEY
Landscape categories: (A) rgf- river gum forest; (B) rgow – river gum open woodland; (C) pb – poplar box; (D) gb – grey box; (E) mix – mixed species; (F) cp - cypress pine; (G) git – grasslands & isolated trees.
Numbers of sites: Argf (5 sites), Brgow (11), Cpb(7), Dgb (2), Emix (6), Fcp (4) and Ggit (4).

By adjusting the data for sample effort per 20-minute sample (Fig 6.7ai), different distribution patterns of highest call abundance emerged. In spring the categories showing highest call abundance included Dgb represented by two only sample sites, and a different decending order - Arg, Dgb, Emix and Cpb. In summer the categories included Fcp and a differing order – Fcp, Argf, Cpb and Emix, and in autumn although still highest in Brgow also included Dgb and an even distribution across Argf, Emix and Cpb. These results showed the importance of a variety in vegetation types across the landscape - Argf and Cpb across all seasons, Dgb in spring and summer, Fcp in summer, Emix in summer and autumn and Brgow in autumn.

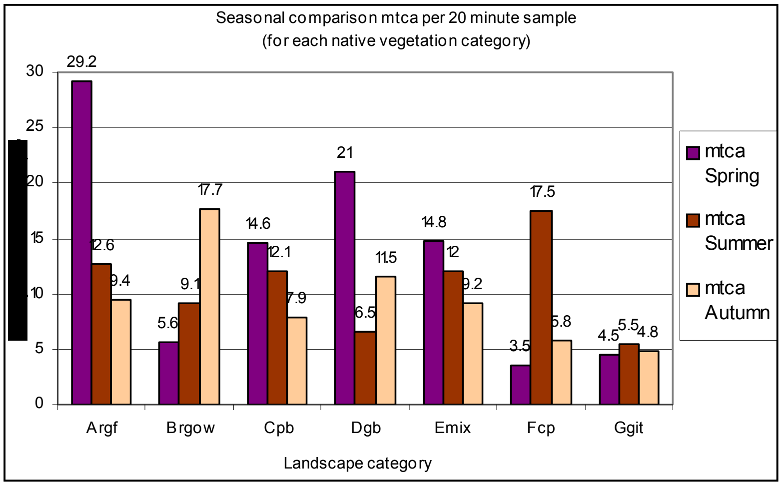


Fig 6.7.ai Seasonal comparisons of microbat total call abundance adjusted for sample effort (ie scores per 20 minute sample for each category)
KEY
Landscape categories: (A) rgf- river gum forest; (B) rgow – river gum open woodland; (C) pb – poplar box; (D) gb – grey box; (E) mix – mixed species; (F) cp - cypress pine; (G) git – grasslands/isolated trees.
Numbers of sites: Argf (5 sites), Brgow (11), Cpb(7), Dgb (2), Emix (6), Fcp (4) and Ggit (4).

For each landscape category seasonal variations in call abundance occurred. Whilst three categories, Argf, Cpb and Emix, showed a seasonal pattern of highest abundance in spring and lowest in autumn, for Dgb highest spring abundance was followed by lowest in summer, not autumn. Two categories, Fcp and Ggit, showed a seasonal pattern of high call abundance in summer and lowest in spring, with an evenness of results for the latter. Conversely Brgow was the only category where a seasonal highest call abundance in autumn and lowest in spring was recorded.

Microbat total feeding buzz abundance (mtfba)
Total feeding buzz abundance was highest in spring and lowest in autumn (287, 197 and 90) with summer and autumn abundance 31% and 69% lower than in spring, constituting a greater seasonal variation than for call abundance. Although generally reflecting

seasonal call abundance patterns, total buzz abundance results varied proportionally from call results as well as between categories and seasons. Data adjusted for sample effort (Fig 6.7aii) showed the highest buzz abundance scores per 20-minute sample across all seasons in decreasing order were for Argf, Cpb, Dgb all in spring, and both Fcp and Cpb in summer. Buzz abundance for Brgow showed the greatest variation from call abundance. Although in spring these landscape categories included the same four landscape categories as for call abundance the order and magnitude differed, in decending order Argf, Cpb Dgb and Emix. In summer the categories included Fcp alog with as Cpb and Emix, and in autumn although very evenly distributed buzz abundance was highest for Fcp.

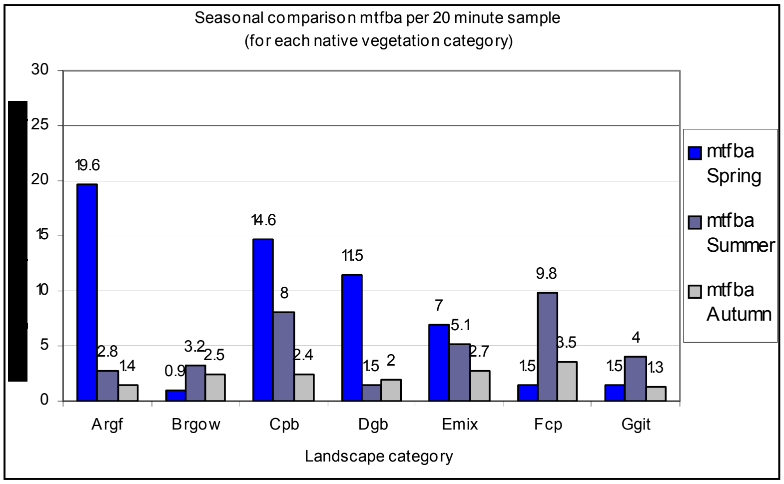


Fig 6.7.aii Seasonal comparisons of microbat total feeding buzz abundance adjusted for sample effort (ie scores per 20 minute sample for each category
KEY
Landscape categories: (A) rgf- river gum forest; (B) rgow – river gum open woodland; (C) pb – poplar box; (D) gb – grey box; (E) mix – mixed species; (F) cp - cypress pine; (G) git – grasslands/isolated trees.
Numbers of sites: Argf (5 sites), Brgow (11), Cpb(7), Dgb (2), Emix (6), Fcp (4) and Ggit (4).

Although the same landscape categories showed similar patterns of seasonal distribution of buzz and call abundance, the seasonal variations were more extreme, and for some categories, very different. Feeding buzz results adjusted for effort showed highest spring and lowest autumn buzz abundance for Argf, Cpb and Emix and although buzz abundance was also highest in spring for Dgb, very low abundance was recorded in both summer and autumn. On the other hand for Brgow high autumn and low spring call abundance shifted to highest summer and lowest spring buzz abundance. The seasonal summer high buzz abundance pattern was also recorded for Fcp and Ggit.

Buzz to call efficiency

Feeding buzz abundance did not necessarily correlate with call abundance, and in many cases feeding buzz abundance was disproportionate to call abundance (Fig. 6.7a). The most outstanding examples where a high call abundance did not correspond with high buzz abundance were, in spring for Brgow where only 10 buzzes were recorded for 62 calls, in summer for both Argf (14 to 63) and Brgow (35 to 100) and in autumn for Argf (7 to 47), Brgow (27 to 195) and Dgb (4 to 23). On the other hand the same number of feeding buzzes were recorded as calls (102) for Cpb in spring and 16 buzzes to 22 calls for Git in summer. Thus the flight/feeding buzz to call ratio, a measurement of feeding efficiency, varied between 13% and 100% efficiency. The landscape category, the microbat total feeding buzz abundance and total call abundance, together with buzz-to-call efficiency percentages are set out in seasons and order of percentage efficiency in Table 6.7a.

Table 6.7.a. A feeding efficiency rating for season and native vegetation landscape category

Season	Landscape Category	mtfba	mtca	% feeding efficiency
spring	Cpb	102	102	100
summer	Ggit	16	22	72
spring	Argf	98	146	67
summer	Cpb	56	85	65
autumn	Fcp	14	23	60
summer	Fcp	39	70	55
spring	Dgb	23	42	54
spring	Emix	42	89	47
summer	Emix	34	72	47
summer	Brgow	35	100	35
spring	Fcp	5	14	35
spring	Git	6	18	33
autumn	Cpb	17	55	31
autumn	Git	6	19	31
autumn	Emix	16	55	29
summer	Dgb	3	13	23
summer	Argf	14	63	22
autumn	Dgb	4	23	17
spring	Brgow	10	62	16
autumn	Argf	7	47	15
autumn	Brgow	27	195	13

KEY: (mtca) microbat total call abundance; (mtfba) microbat total feeding buzz abundance
Landscape categories: (A) rgf- river gum forest; (B) rgow – river gum open woodland; (C) pb – poplar box;
(D) gb – grey box; (E) mix – mixed species; (F) cp - cypress pine; (G) git – grasslands & isolated trees.

The highest feeding buzz to calls efficiency ratio (100%) was recorded for poplar box in spring. The seven landscape categories in which the most efficient feeding percentages were recorded were poplar box in spring and summer, river gum forest and grey box in spring, grasslands in summer, and cypress pine in summer and autumn. The seven landscape categories in which the least efficient feeding percentages were recorded were river gum open woodland in spring and autumn, grey box and river gum forest in summer and autumn, and grasslands in autumn.

Insect total call abundance (itca)
In contrast to microbat calls, insect total call abundance was lowest in spring (54) and highest in summer (166), the autumn total (91) being lower than both summer and spring by 66% and 45% respectively.

Data adjusted for sample effort (Fig 6.7aiii) showed the highest insect call abundance per 20-minute sample were recorded predominantly during summer, in decreasing order for: grassland and isolated tree, cypress pine, grey box, rivergum forest, and mixed remnant categories, and in autumn for poplar box.

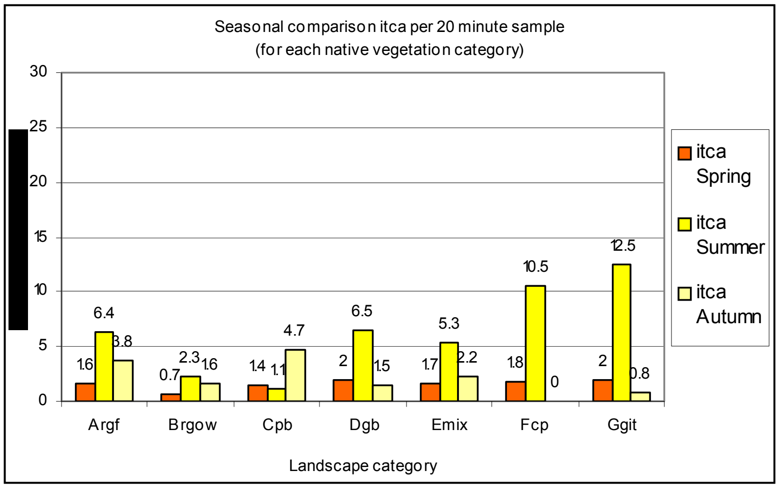


Fig 6.7.aiii Seasonal comparisons of insect total call abundance adjusted for sample effort (ie scores per 20 minute sample for each category
KEY
Landscape categories: (A) rgf- river gum forest; (B) rgow – river gum open woodland; (C) pb – poplar box;
(D) gb – grey box; (E) mix – mixed species; (F) cp - cypress pine; (G) git – grasslands/isolated trees.
Numbers of sites: Argf (5 sites), Brgow (11), Cpb(7), Dgb (2), Emix (6), Fcp (4) and Ggit (4).

Seasonal comparisons of insect total call abundance showed a pattern of highest in summer and lowest in spring for Argf, Brgow and Emix remnant categories. Only for Brgow was this a replication of the seasonal pattern for microbat call and buzz abundance. Highest insect call abundance in summer and lowest in autumn was recorded for both Ggit and Dgb, and highest in autumn and lowest in summer for Cpb.

There may to be some relationship between insect call abundance and microbat call and buzz abundance. Troughs in insect call abundance co-incided with high microbat call and buzz abundance in summer for Cpb. A coincidence of peaks in insect call abundance and high levels of microbat call and buzz abundance were recorded in summer for Argf and in autumn for Cpb. These relationships are however associations between calling insects and bat activity and represent the results from a combination of sites.

Influence of individual sites

Absence

Absence of calls and buzzes at individual sites influenced the results shown in Fig 6.7a and also provided a demonstration of seasonal spatial variations in microbat and insect activity. For each native vegetation landscape category, the number of sample sites and the percentage of sites within the sample recording absence, and a seasonal total of absence for microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca), are set out in Table 6.7b.

In spring microbat calls were recorded at all sample sites. In both summer and autumn, calls were absent from only two sites, resulting in only a 3.1% absence from total sites. The summer sites included one each for Brgow and Emix, and the autumn one each for Brgow and Cpb.

Table 6.7.b. Seasonal comparison of absence of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca) at sites for each native vegetation landscape category (sample number of total 64 sites)

Season/ calls and buzzes	(A)rgf (5 sites) % absence	(B)rgow (11sites) % absence	(C)pb (7 sites) % absence	(D)gb (2 sites) % absence	(E)mix (6 sites) % absence	(F)cp (4 sites) % absence	(G)git (4 sites) % absence	Total (39 sites) % absence
Spring								
mtca	0	0	0	0	0	0	0	0
mtfba	**80**	64	**43**	0	16.7	**50**	**50**	**29.7**
itca	20	**55**	**43**	0	33	**50**	25	**23.4**
Summer								
mtca	0	9	0	0	17	0	0	3.1
mtfba	0	18	14	0	33	25	**50**	12.5
itca	20	**45**	28	0	**50**	**75**	25	**25**
Autumn								
mtca	0	9	14	0	0	0	0	3.1
mtfba	**40**	18	28	0	0	0	**50**	14
itca	**60**	27	14	**50**	0	**50**	25	17.2

KEY : (Red) >76% absence; (Orange) 60%-75%absence; (Yellow) 50%-59% absence; <49% absence
Landscape categories: (A) rgf- river gum forest; (B) rgow – river gum open woodland; (C) pb – poplar box; (D) gb – grey box;
(E) mix – mixed species; (F) cp - cypress pine; (G) git – grasslands & isolated trees.

Microbat feeding buzzes however were absent from 29.7% of all spring sites, 12.5% of all summer sites and 14% of all autumn sites. The highest absence of buzzes for individual categories was recorded, in spring from 80% of Argf sites, 64% of Brgow, 50% of Fcp and Ggit sites and 43% of Cpb sites; in summer from 50% of Git sites and 33% of Emix sites; in autumn from 28% of Cpb sites. The categories recording zero absence of buzzes were Dgb in all seasons, Argf in summer and Emix and Fcp in autumn.

Although the Dgb category represents results from only two sample sites, zero absence of both microbat calls and buzzes across the three seasonal surveys was recorded. At the other extreme at Argf zero absence of microbat calls in spring, summer and autumn, but an 80% and 40% absence of buzzes in spring and autumn was recorded. For several other vegetation categories zero absence of calls but high percentage absence of buzzes was recorded – in spring Brgow (0 calls -64% buzzes), Fcp (0-50%), and Cpb (0-43%), and Ggit in spring, summer and autumn (0-50%).

Insect calls were absent from 23.4% of sites in spring, 25% of sites in summer and 17.2% of sites in autumn. The highest absence of insect calls at individual landscape categories was recorded, in decreasing order, from 75% of Fcp sites in summer, 60% of Argf in autumn, and 55% of Brgow sites in spring. Conversely the greatest presence of insect calls was recorded at 100% of both Dgb sites in spring and summer, and Emix sites in autumn, 86% of Cpb sites in autumn, and 80% of Argf sites in both spring and summer.

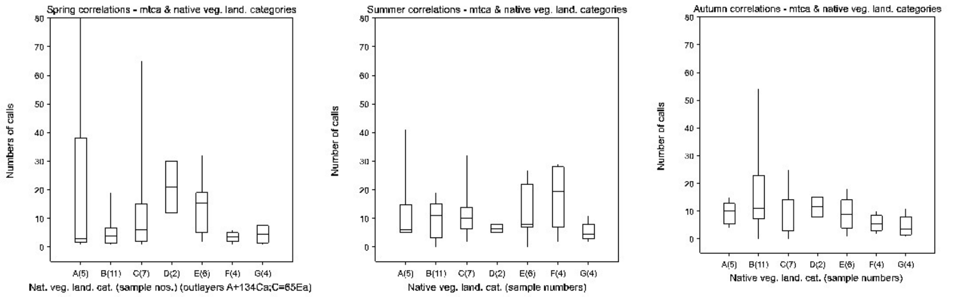
Maximum and mean

A seasonal comparison of the maximum, minimum, median and quartiles for microbat total call abundance, microbat total feeding buzz abundance and insect total call abundance for the seven native vegetation landscape categories is set out in Fig. 6.7b.

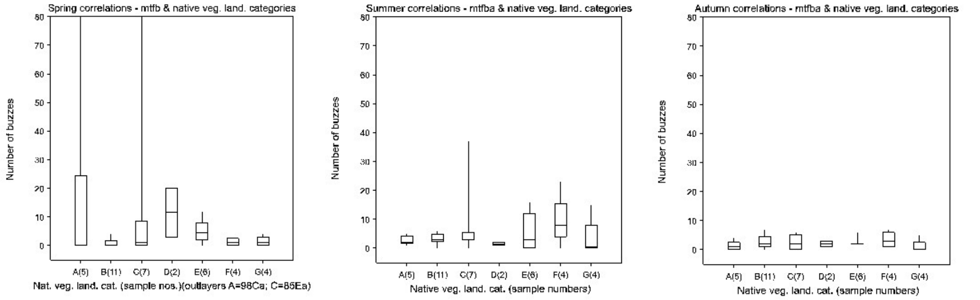
The landscape categories most influenced by the results from individual sites (Fig. 6.7b) were: for microbat call abundance in spring and summer, Argf and Cpb and in autumn Brgow and Cpb; for microbat buzz abundance in spring Argf and Cpb and in summer Cpb; for insect call abundance in summer, Ggit.

Microbat calls

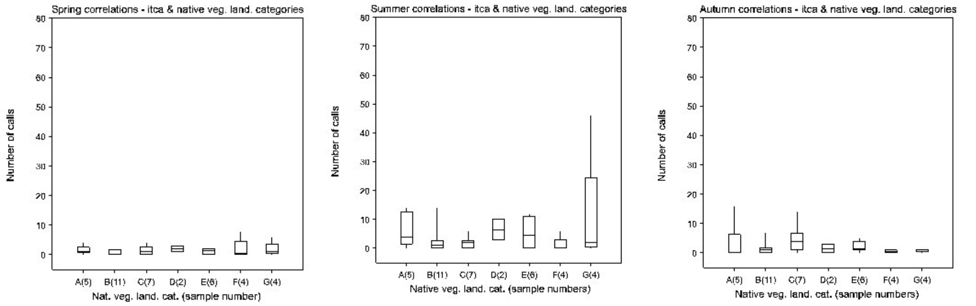
The highest maxima microbat call abundance recorded at individual sites were: in spring for Argf (134), Cpb (65); in summer more evenly for Argf (41), Cpb (32), Fcp (29), and Emix (27); in autumn for Brgow (54), Cpb (25). The Argf site Ca recorded high call abundance across all seasons, the Cpb site Ea and the Emix site Cd recorded high call abundance in spring and autumn and different Dgb sites recorded high call abundance in spring and autumn.



Microbat total call abundance



Microbat total feeding buzz abundance



Insect total call abundance

Fig. 6.7.b. Seasonal comparison of microbat total call abundance, microbat total feeding buzz abundance, insect total call abundance and native vegetation landscape categories, using maximum, minimum, median, quartiles.
Vegetation categories are: : (A) river gum forest; (B) river gum open woodland; (C) poplar box; (D) grey box; (E) mixed species; (F) cypress pine; (GIT) grasslands/isolated trees. (Figures in brackets is sample size).

The highest means of microbat total call abundance were recorded in spring for Argf (29), and Dgb (21), in summer for Fcp (17.5), Argf (12.6), Cpb (12.1) and Emix (12) and in autumn for Brgow (17.7), and Dgb (11.5). High seasonal means were recorded for

Argf and Emix across the three seasons, Dgb in spring and autumn, Cpb in spring and summer and Fcp in summer.

Microbat buzzes

The highest maxima feeding buzz abundance scores recorded at individual sites were: in spring for Argf (98), Cpb (85), in summer more evenly for Cpb (37), Fcp (23), Emix (16), and Ggit (15), in autumn for Brgow (7), Fcp (7), Cpb (6) and Emix (6). High maximum buzz abundance was recorded for Cpb site Ea and Emix site Cd in spring, one Fcp site in spring and autumn, one Dgb site in spring, two Ggit sites in summer, and one Emix site in autumn.

The highest means of total buzz abundance recorded were, in spring for Argf (19.6 buzzes), Cpb (14.6), and Dgb (11.50), in summer Fcp (9), Cpb (8), and in autumn Fcp (3.5) and Emix (2.67). High seasonal mean of total buzz abundance were recorded for Cpb for all three seasons, Fcp and Emix in summer and autumn, Argf and Dgb in spring, Ggit in summer, and Brgow in autumn.

Feeding efficiency

A feeding efficiency percentage was given for individual sites where high scores for both microbat buzz abundance and call abundance had been recorded. Although both call abundance and buzz abundance varied, the highest buzz to call efficiency percentages at individual sites for the following categories: in spring Cpb (130%, 85 buzzes to 65 calls), Argf (73%, 98/134) and Dgb (66%, 20/30), in summer Ggit (135%, 15/11), Cpb (115%, 37/32), Fcp (79%, 23/29) and Emix (73%, 16/22) and in autumn Fcp (70%, 7/10) and Cpb (24%, 6/25).

The buzz to call efficiency percentages for categories recording highest mean for both total buzz abundance and total call abundance were, in spring 100% for Cpb (14.6/14.6), 67.5% for Argf (19.6/29), 54.7% for Dgb (11.5/21) and in summer 66% for Cpb (8/12) and 51.4% for Fcp (9/17.5).

Insect calls

The highest seasonal maxima insect call abundance recorded at individual sites were in spring for Fcp (8) and Ggit (6), in summer for Ggit (46), Argf (14), Brgow (14) and Emix (12), and in autumn for Argf (16), Cpb (14) and Brgow (7**.** Although none of the site results were replicated across seasons, three landscape categories duplicated results for highest maximum insect call abundance - Ggit in spring and summer and Argf and Brgow in summer and autumn.

Although generally higher in summer, high means of insect total call abundance were recorded for Ggit in spring and summer, for Argf and Emix in summer and autumn, Dgb in summer, and Cpb in autumn.

6.7.2 BATS IN THE INTENSIVE FARMING LANDSCAPE

Seasonal distribution

This section compares the results for intensive management categories across three seasons. For each intensive farming landscape category a seasonal comparison of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca) is set out in Fig. 6.7c. The sample effort representing the percentage of the study area landscape for each intensive farming landscape category, is replicated for each season.

Microbat total call abundance (mtca)

For the intensive farming landscape categories the distribution of mtca varied between categories and between seasons. In contrast to the predominance in total call abundance recorded in spring for native vegetation categories, the predominance of calls for these farming landscape categories was recorded in summer (187) with call reductions of 29% and 49% in spring (132) and autumn (95) respectively.

The most evenly distributed call abundance was in autumn with the lowest overall call abundance spread across all three categories, lowest for Hic. Whilst the summer highest seasonal total call abundance was concentrated in Hic, with decreased abundance for Iws and Jdc, spring abundance was concentrated in Hic with decreased abundance for Jdc.

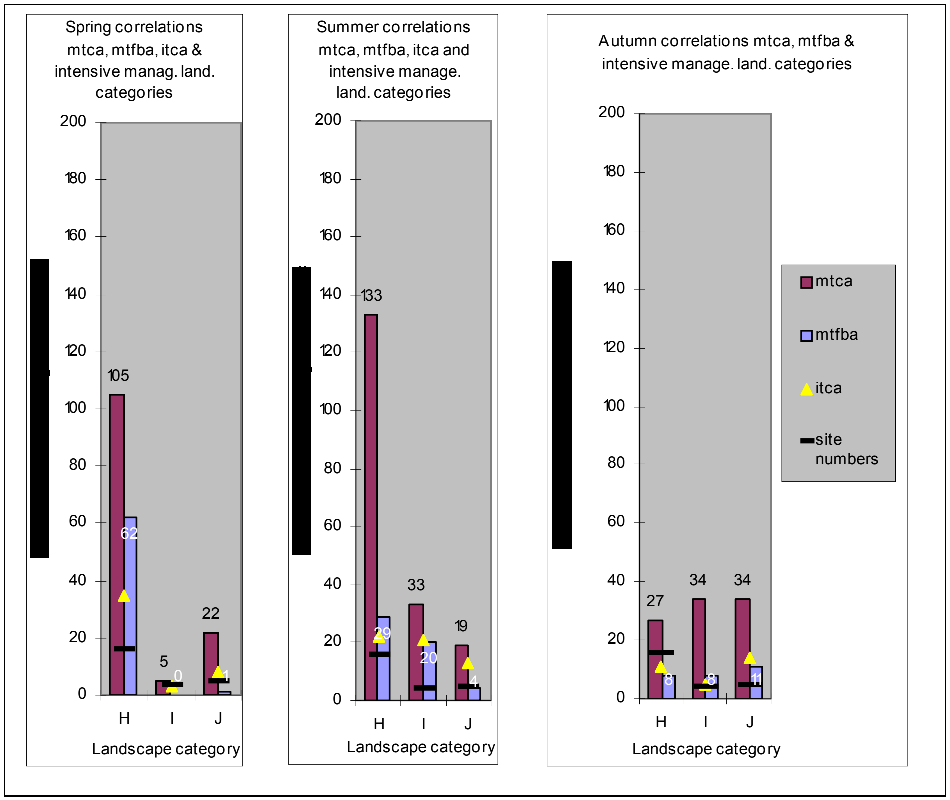


Fig. 6.7.c. Seasonal comparison of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba), and insect total call abundance (itca) for intensive management landscape categories.
KEY: Landscape categories: (H) ic – irrigated cropping; (I) ws – water storage; (J) dc – dryland cropping
Numbers of sites: Hic (16 sites), Iws (4 sites), Jdc (5 sites)

Data adjusted for effort (Fig 6.7ci) showed very different, and a much more even, distribution of call abundance. Although spring abundance was still highest for the irrigated cropping category, the variation was much reduced. Summer abundance was evenly distributed between Hic and Iws with abundance reduced for Jdc. Autumn distribution did however show lower call abundance for Hic after cotton had been picked and higher call abundance for Iws and Jdc. Call abundance was highest, for irrigated cropping in summer and spring during cotton production, for water storages in autumn and summer, and for dryland cropping in autumn.

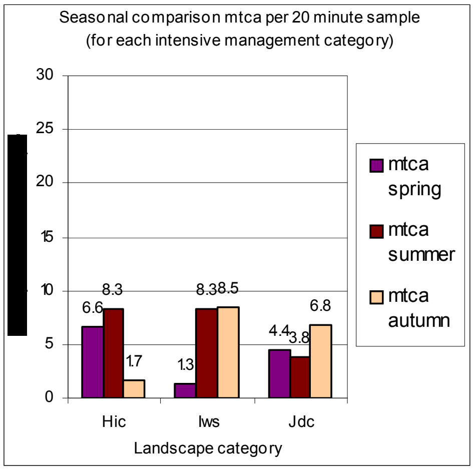


Fig 6.7.ci Seasonal comparisons of microbat total call abundance adjusted for sample effort (ie scores per 20 minute sample for each category)
KEY **Landscape categories**: (H) ic irrigated cropping; (I)ws water storage; (J)dc dryland cropping
Numbers of sites: Hic (16 sites); Iws (4 sites); Jdc (5 sites)

Microbat total feeding buzz abundance

The seasonal bias in the distribution of microbat total feeding buzz abundance for these categories (Fig. 6.7.c) was the same as for the native vegetation categories - 62 in spring, 53 in summer and 27 in autumn. Summer and autumn buzz abundance was 15% and 66% respectively lower than in spring.

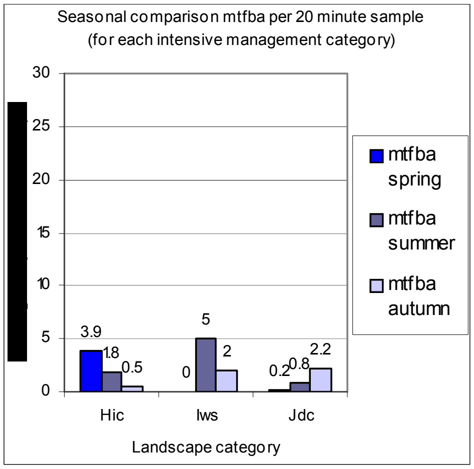


Fig 6.7.cii Seasonal comparisons of microbat total feeding buzz abundance adjusted for sample effort (ie scores per 20 minute sample for each category)
KEY **Landscape categories**: (H) ic irrigated cropping; (I)ws water storage; (J)dc dryland cropping
Numbers of sites: Hic (16 sites); Iws (4 sites); Jdc (5 sites)

Data adjusted for sample effort (Fig. 6.7.cii) shows feeding buzz abundance in spring was highest for Hic, in summer for Iws, and evenly distributed between Iws and Jdc in autumn. Like the native vegetation categories, high microbat call abundance was not necessarily accompanied by high feeding buzz abundance. However for these farming categories the buzz abundance results were very different from those for call abundance the most noticable disjunctions being for Hic in summer and Iws in autumn. These results suggest that the availability of appropriate insect populations were highest in spring for irrigated cropping sites, in summer for water storage sites and in autumn for water storages and dryland cropping sites.

Buzz and call efficiency

Although for Hic the summer call abundance (133) was higher than spring call abundance (105), the buzz to call relationship was much stronger in both spring and autumn, than in summer (Table 6.7c). For Iws even though the highest call abundance was recorded in autumn the buzz to call relationship was much stronger in summer than autumn.

The buzz-to-call ratios, as a measurement of flighy/feeding efficiency, are set out in order of efficiency in Table 6.7c. The percentages of feeding efficiency ranged from the most efficient of 61% (summer Iws), through 59% (spring Hic), 32% (autumn Jdc), and 30% (autumn Hic), to the least efficient of 19% (summer Jdc), 4.5% (spring Jdc), and 0% (spring Iws).

Table 6.7.c. A feeding efficiency rating for season and intensive management landscape categories

Season	Landscape category	mtfba	mtca	% feeding efficiency
summer	Iws	20	33	61
spring	Hic	62	105	59
autumn	Jdc	11	34	32
autumn	Hic	8	27	30
autumn	Iws	8	34	24
summer	Hic	29	133	22
summer	Jdc	4	21	19
spring	Jdc	1	22	4.5
spring	Iws	0	5	0

KEY: (mtca) microbat total call abundance; (mtfba) microbat total feeding buzz abundance
Landscape categories: (Hic) irrigated cropping; (Iws) water storage; (Jdc) dryland cropping

The four farming categories that recorded the highest and most efficient flight/feeding percentages (>30%) included, one summer (Iws), one spring (Hic) and two autumn results (Jdc and Hic). The five categories that recorded the least efficient feeding percentages (<25%) included two spring (Iws and Jdc), two summer (Jdc and Hic) and one autumn (Iws). The highest autumn levels of efficiency would suggest that in autumn foraging activity prior to hibernation may require high energy resource efficiency, or that insects are slower or respond to ultrasound less quickly.

Insect total call abundance

Insect total call abundance for these categories, as for the native vegetation categories, was highest in summer, however it was lowest in autumn rather than spring. The summer insect call abundance (56) was 18% higher than in spring (46), and 45% higher than in autumn (30). This high summer seasonal bias reflected microbat buzz abundance results but not microbat call abundance results.

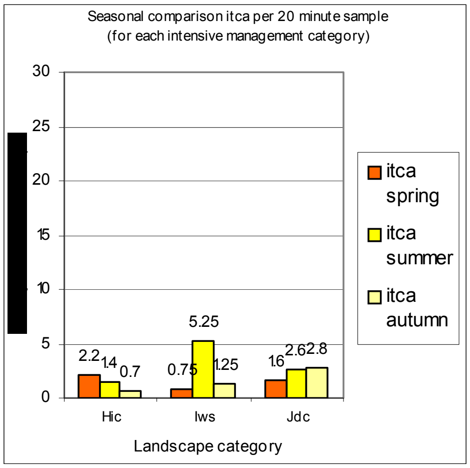


Fig. 6.7.ciii Seasonal comparisons of insect total call abundance adjusted for sample effort (ie scores per 20 minute sample for each category)
KEY **Landscape categories**: (H) ic irrigated cropping; (I)ws water storage; (J)dc dryland cropping
Numbers of sites: Hic (16 sites); Iws (4 sites); Jdc (5 sites)

Data adjusted for sample effort revealed the landscape categories that recorded the highest insect call abundance were water storages in summer, with similar levels recorded for Hic in spring, and Jdc in summer and autumn. For each of the farming categories, seasonal patterns in insect call abundance differed. Insect call abundance althought fairly even for Hic was highest in spring and lowest in autumn, for Iws highest in summer and similarly low in spring and autumn, and for Jdc lowest in spring.

However there would appear to be some relationship between these insect call abundance results and the microbat feeding efficiency ratings set out in Table 6.7c. Three of the category/seasonal landscape combinations that recorded the highest insect call abundance also recorded the highest feeding efficiency ratings (Iws summer 61%, Hic spring 59%, and Jdc autumn 32%), suggesting a possible relationship between microbat activity and populations of calling insects. Conversely two summer categories that recorded high seasonal insect call abundance recorded low (<25%) flight/feeding efficiency percentages - Hic (22%), and Jdc (19%). These later results might suggest (i) that insects were utilising calls as a warning or interference strategy (Fullard *et al*. 1994, Faure and Hoy 2000, Greenfield and Baker 2003, Hristov and Conner 2005), and (ii) the effectiveness of insect calls. These relationships between insect calls and microbat activity would however need to be examined at the finer individual site level.

Influence of individual sites

Absence

The absence of calls and buzzes at individual sample sites shown in Fig. 6.7.c. demonstrated seasonal spatial variations in microbat and insect activity. For each intensive management landscape category the number of sample sites and percentage of sites within the sample registering absence of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca) are set out in Table 6.7d.

Table 6.7.d. Seasonal comparison of % absence of mtca, mtfba and itca at sites for each native vegetation landscape category

	(H)ic (16 sites) % absence	(I)ws (4 sites) % absence	(J)dc (5 sites) % absence	Total (64) sites) % absence
Spring				
mtca	12.5	25	0	4.68
mtfba	37.5	100	80	21.9
itca	56	25	40	18.8
Summer				
mtca	6.3	25	40	6.3
mtfba	31	25	60	14
itca	31	75	40	15.6
Autumn				
mtca	25	0	40	9.4
mtfba	62	50	40	21.9
itca	56	25	20	17.2

KEY: (mtca) microbat total call abundance; (mtfba) microbat total feeding buzz abundance; (itca) insect total call abundance.
(Red) highest absence; (Orange) second highest absence
Landscape categories: (Hic) irrigated cropping; (Iws) water storage; (Jdc) dryland cropping.

Microbat call abundance was present at 93.7% and 87.5% of Hic sites in summer and spring but absent from 40% of Jdc sites in summer and autumn, and from 25% of Iws sites in spring and summer and Hic sites in autumn.

Althought buzzes were present at 75% of Iws sites in summer and 62.5% and 69% of Hic sites in spring and summer, buzz abundance was absent from 100% and 50% of Iws sites in spring and autumn, 80% and 60% of Jdc sites in spring and summer and 62% of Hic sites in autumn. Dryland fields (Jdc) in all seasons were either fallow, in spring recently harvested, or in autumn ploughed ready for wheat planting; cotton crops (Hic) in autumn had been either defoliated and/or picked.

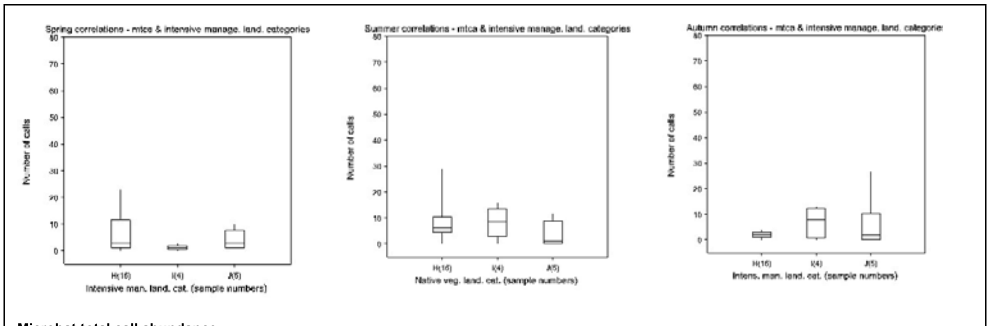
Insect calls however were present at 69% of Hic sites in summer, 75% of Iws sites in spring and autumn, and 80% of Jds sites in autumn, but absent from 75% of Iws sites in summer, 56% of Hic sites spring and autumn and 40% of Jdc sites in both spring and summer.

Summing up microbat calls were absent from 4.7% of all spring sample sites, 6.4% of all summer sample sites and 9.4% of all autumn sample sites. In comparison microbat feeding buzzes were absent from 21.9% of all spring and autumn sample sites and 14% of all summer sample sites. The absence of buzzes was 4.5 times higher in spring and 2.25 higher in summer and autumn than the absence of calls. Food resources may have been less available or flight less related to prey search in spring. Insect calls were absent from 18.8% of spring sample sites, 15.6% of summer sample sites and 17.2% of autumn sample sites.

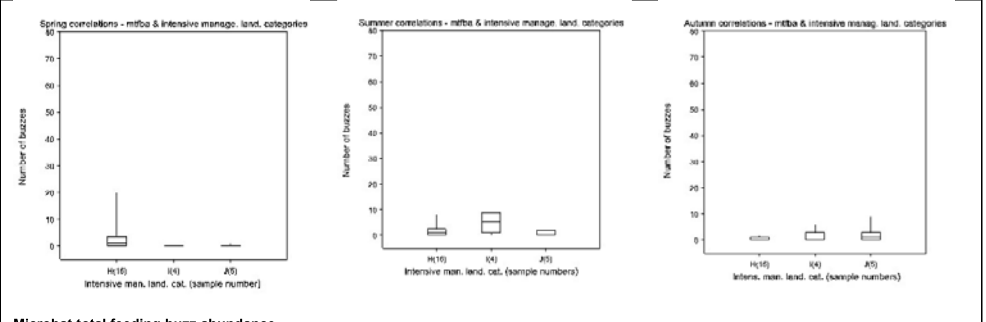
Maximum and mean

A seasonal comparison of the maximum, minimum, median and quartiles for microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca) for the three intensive management landscape categories is set out in Fig. 6.7d.

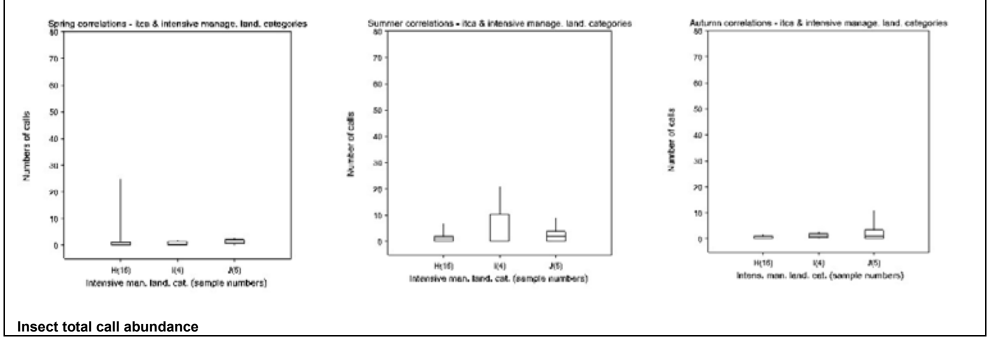
The categories most influenced by the results at individual sites were: for microbat total call abundance, Hic in spring and summer and Jdc in autumn; for microbat total feeding buzz abundance Hic in spring; for insect total call abundance Hic in spring and possibly Iws in summer. The highest maxima microbat call abundance recorded was for two Hic sites, in summer (29) and in spring (23). High microbat call abundance for Hic was recorded at three other sites in spring (19, 18, 15) and at four other sites in summer (17, 14, 11, 10). The highest mean of microbat total call abundance was, for Hic in summer (8.3), for Jdc in summer (8.25), and for Iws in autumn (6.8).



Microbat total call abundance



Microbat total feeding buzz abundance



Insect total call abundance

Fig. 6.7.d. Seasonal comparison of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba), insect total call abundance (itca) and intensive management landscape categories, using maximum, minimum minimum, median, and quartiles.
Vegetation categories: (H) irrigated cropping; (I) water storage; (J) dryland cropping. (Figures in bracket: sample number of sites).

The highest maxima microbat feeding buzz abundance recorded in spring was for an Hic site (20), in summer for an Iws (9), and in autumn for Jdc (9). In spring two other Hic sites recorded high maximum buzz abundance (17, 11). The highest mean of total feeding buzz abundance was, in spring for Hic (3.8), in summer for Iws (5.5), and in autumn for Jws (2.2).

The highest maxima insect call abundance recorded was for an Hic site in spring (25), but Hic recorded the lowest maxima in summer (7), and autumn (2). For Iws sites the highest maxima was in summer (21), and for Jdc sites in autumn (11). The highest seasonal mean of insect total call abundance was recorded in spring for Hic (2.19), in summer for Iws (5.25), and in autumn for Jdc (2.6).

Cotton varieties

Of the sixteen (Hic) irrigated cropping sample sites, four were at fields of the two gene Bt Bolgard II™ cotton variety, eleven were at fields of Conventional cotton varieties, and one site was within fallow fields (Table 6.7e). This representation reflected the percentages of Conventional and Bt cotton varieties planted that year.

Table 6.7.e. Seasonal comparisons of Hic sites - microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba), insect total call abundance (itca), and Conventional and Bt (Bolgard II™) cotton varieties.

Sample site		Spring				Summer				Autumn			
Cotton Variety and sample site	Adjacent Category	Sample time	mtca	mtfba	itca	Sample time	mtca	mtfba	itca	Sample time	mtca	mtfba	itca
Bolgard II™													
Hf	mid cotton/Conv.	6	1	0	0	3	14	1	2	1	3	0	1
En	fallow/cotton	7	1	0	0	2	6	1	1	6	2	1	1
Ee	fallow	4	8	4	1	2	5	4	1	6	1	2	1
Eo	roadway	8	3	3	0	1	0	0	7	8	1	0	0
Conventional													
Ha	mid cotton	1	0	0	1	4	2	1	1	5	3	0	2
Hd	mid cotton	5	2	2	0	4	17	0	2	2	0	0	1
Hb	mid cot/Ingard	2	18	11	0	5	1	0	2	4	1	1	0
Ak	Cpb&water chan.	2	15	2	4	7	9	8	0	7	2	0	0
Hh	Cpb	8	3	1	0	1	5	2	0	4	2	0	2
Em	Brgow&water	3	19	17	1	3	29	3	2	8	0	0	0
Ec	Brgow	6	5	1	0	6	10	1	1	2	0	0	1
He	isolated field/Git/W	3	3	1	1	2	5	0	2	5	3	0	0
Eh	fallow	2	23	20	2	3	11	6	0	7	4	1	0
Bk	fallow	3	3	0	0	8	4	0	0	6	2	2	0
Aq	fallow	1	1	0	0	4	8	0	1	2	0	0	1
Fallow													
Ao	fallow	6	0	0	0	3	7	2	0	1	3	1	1

KEY: (Lemon) <4; (Yellow) 4-7; (Orange) 8-14; (Red) >14

One of the Conventional variety sites in spring, one of the Bolgard II™ sites and the fallow site in summer, recorded zero for both microbat call abundance and feeding buzz abundance. Two Conventional sites - one spring and one summer - and two spring Bolgard II™ sites recorded one call and zero buzzes. Four Conventional sites in spring and one in summer, recorded call abundance between 2 and 4 and buzz abundance of between 0 and 2.

On the other hand, in spring four of the Conventional variety sites recorded high microbat call abundance of between 15 and 23 calls; of these three sites recorded correspondingly high buzz abundance between 11 and 20 buzzes. In summer two Conventional variety sites recorded high call abundance of between 17 and 29, four sites recorded between 8 and 11 calls and two sites recorded 5 calls. The corresponding buzz abundance results in summer were between zero and eight buzzes.

Four of the eleven Conventional variety sites were however located adjacent to native vegetation remnants. In spring two of these sites recorded high call abundance (15 and 19) and buzz abundance (2 and 17) and in summer all four sites recorded mid to high call abundance (5, 9, 10 and 29 calls) and a corresponding range of buzz abundance (2, 8, 1 and 3). Nevertheless the other Conventional variety sites that recorded high call abundance, two in spring and three in summer, were located either in the middle of cotton fields or adjacent to fallow fields. The two sites in spring recorded 18 and 23 calls and 11 and 10 buzzes, the three in summer recorded 17, 11 and 8 calls and 0, 6 and 0 buzzes.

In contrast, the four Bolgard II™ variety sites recorded considerably lower levels for both call and buzz abundance. The one exception was a summer site where a call abundance of 14 was accompanied by one buzz. Two sites in spring recorded 3 and 8 calls and 3 and 4 buzzes respectively, and one of these sites in summer recorded 5 calls and 4 buzzes, and another 6 calls and one buzz. The Bolgard II™ sites were adjacent to either fallow or cotton fields or a roadway.

From a summary of these results corrected for sample effort is displayed in Table 6.7ei below it is clear that in spring and summer during crop production microbat call abundance was higher at Conventional sites than Bolgard II™ sites. Feeding buzz abundance although higest at Conventional sites in spring was highest at the fallow site in both summer and autumn. Insect calls were highest at Conventional sites in spring, Bolgard II™ sites in summer and the fallow site in autumn. As the Bt variety Bolgard II™ resists *Helicoverpa* species, which over time results in smaller populations of *Helicoverpa* species, the lower intensities of call and buzz abundance recorded at Bolgard II™ sites would suggest that any microbat call and feeding buzz activity over cotton fields is probably related to populations of *Helicoverpa.*

Table 6.7.ei. Seasonal comparisons of Hic sites - microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba), insect total call abundance (itca), and Conventional and Bt (Bolgard II™) cotton varieties.

Hic Field (sites)	Bol. II (n=4)	Con. (n=11)	Fal. (n=1)	Bol. II (n=4)	Con. (n=11)	Fal. (n=1)	Bol. II (n=4)	Con. (n=11)	Fal. (n=1)
Call type	mtca	mtca	mtca	mtfba	mtfba	mtfba	itca	itca	itca
Spring	3.25	**8.36**	0	1.75	**5.0**	0	0.25	**0.8**	0
Summer	6.00	**9.18**	7	1.50	1.9	**2**	**2.25**	1	0
Autumn	1.75	**4.80**	3	0.75	0.1	**1**	0.75	0.63	**1**

Some possible contributing factors to the variations in bat activity are, differences in cotton varieties, differences in adjacent landscape categories, recent irrigation, fields of regularly high or low moth activity (pers. communication with growers), varying *Helicoverpa* associated insect populations and hot spots in insect activity (MacKinnon 2005 unpublished).

6.7.3 BATS IN CULTURAL LANDSCAPES

Seasonal distribution

A seasonal comparison of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba) and insect total call abundance (itca) for the combined ten (native vegetation and intensive management) landscape categories is set out in Fig. 6.7e. Distribution of microbat and insect activity varied seasonally and between categories.

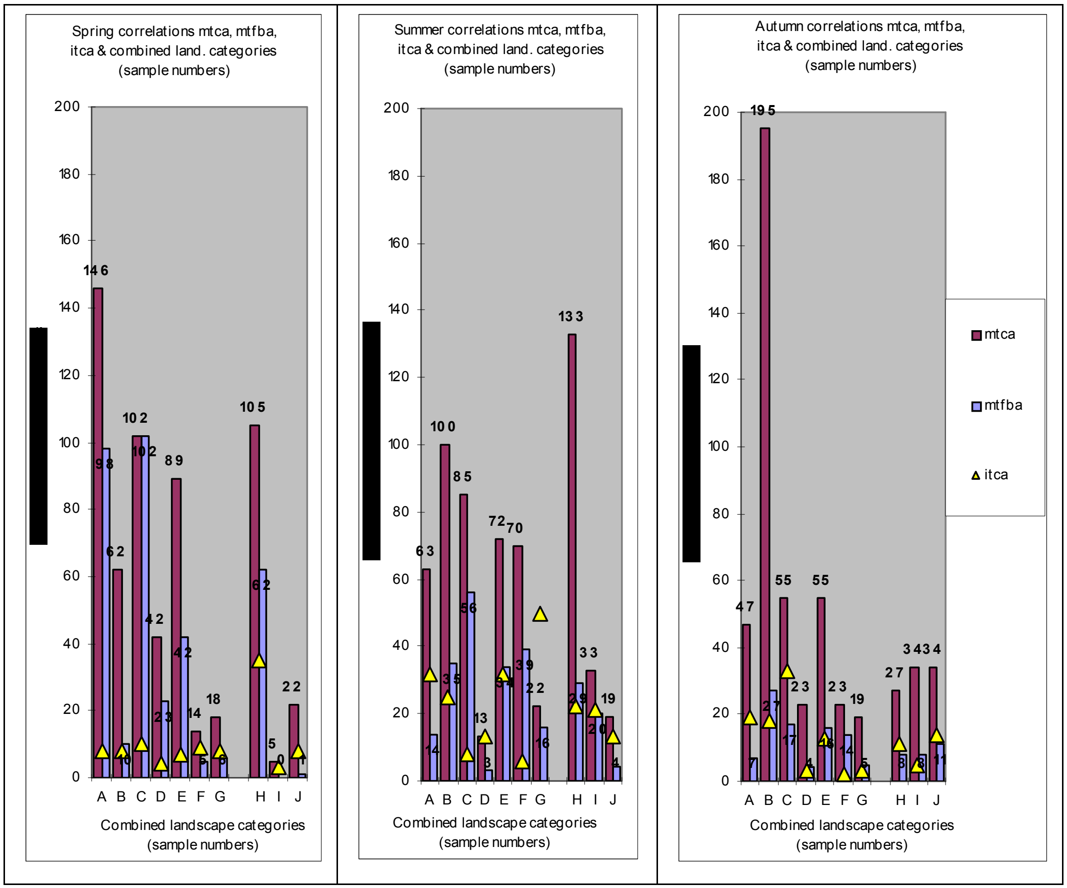


Fig. 6.7. e. Seasonal comparison of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba), and insect total call abundance (itca) for the combined native vegetation and intensive management landscape categories.
KEY: Landscape categories & numbers of sites:
Native vegetation : (A) river gum forest (5); (B) river gum open woodland (11); (C) poplar box (7); (D) grey box (2);
(E) mixed species (6); (F) cypress pine (4); (G) grassland and isolated trees (4);
Intensive management: (H) irrigated cropping (16); (I) water storage (4); (J) dryland cropping (5.)

Microbat total call abundance (mtca)

Across the combined landscape there was little variation in mtca between spring and summer (605 and 610) but in autumn total call abundance decreased by 16% to 512.

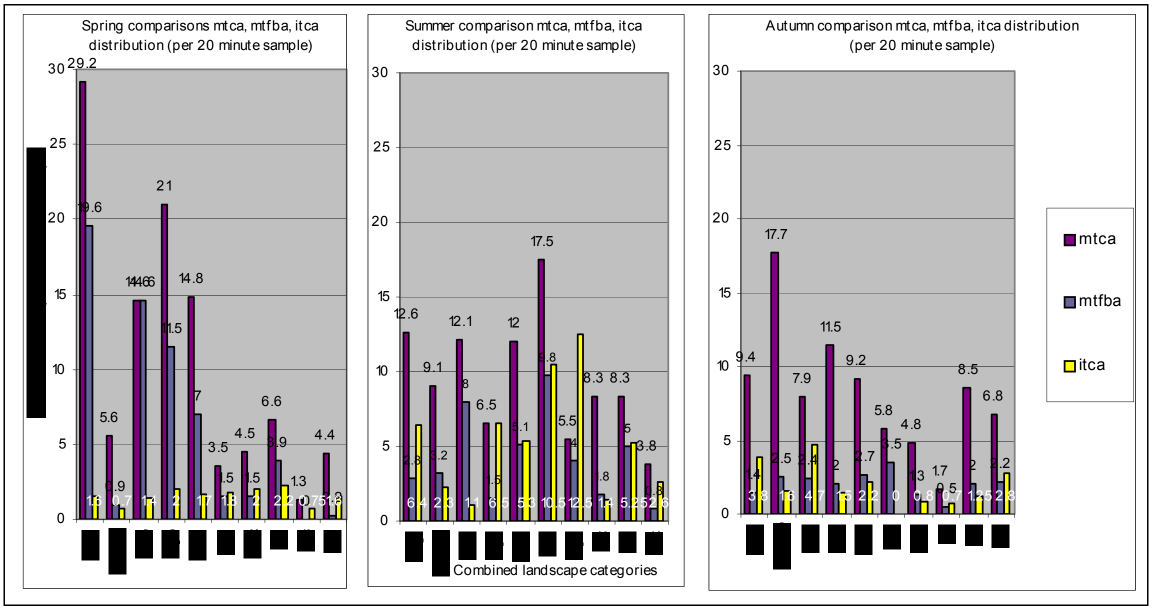


Fig. 6.7. ei. Seasonal comparison of microbat total call abundance (mtca), microbat total feeding buzz abundance (mtfba), and insect total call abundance (itca) adjusted for sample effort for the combined native vegetation and intensive management landscape categories.
KEY: Landscape categories & numbers of sites:
Native vegetation : (A) river gum forest (5); (B) river gum open woodland (11); (C) poplar box (7); (D) grey box (2);
(E) mixed species (6); (F) cypress pine (4); (G) grassland and isolated trees (4);
Intensive management: (H) irrigated cropping (16); (I) water storage (4); (J) dryland cropping (5.)

From data for all ten landscape categories adjusted for sample effort (Fig. 6.7ei) the highest spring call abundance distributed across Argf then Dgb, Emix, Cpb and Hic, shifted in summer to an activity peak for Fcp and lower equal distribution across Argf, Cpb and Emix as well as Brgow, Hic and Iws, and shifted in autummn to a peak in activity for Brgow and spread across Dgb then Argf, Emix, Iws then Cpb and Jdc. These categories did not include Iws in spring Jdc in summer and Hic in autumn.

Feeding buzz abundance differed seasonally from call abundance in order and magnitude with highest buzzes in spring for Argf, followed by Cpb, Dgb, Emix and Hic, shifting in summer to Fcp, followed by Cpb, Emix, Iws and Ggit, and much lower even autumn distribution for Fcp, Emix, Dgb, Iws and Jdc. Thus the importance of different native vegetation and intensive management categories for foraging oscillated seasonally and included intensive management categories in summer and autumn more than in spring.

Insect call abundance on the other hand was highest in summer spread in decending abundance across Ggit, Fcp, Argf, Dgb, Emix and Iws. The greatest interaction between insects and microbats would appear to have been for Ggit, Fcp, Argf, Dgb and Emix as well as Iws in summer, Hic in spring, and Cpb, Argf and Jdc in autumn.

Co-existence

The seasonal variations in distribution of microbat activity across and between differing elements of the cotton production landscape could be associated with some of the management practices across these landscapes.

When both summer and winter crops are picked or harvested and fields are prepared for consequent winter or summer crops or fallows, autumn and very early spring become the times of great disturbance of insect populations. With crop habitat removed resident insects are forced to relocate or die, hence possibly increasing insect populations in native vegetation landscape elements particularly in autumn (eg. Brgow and Dgb). *Helicoverpa* spp. pupae-busting required before Septemeber however captures overwintering moths only in cotton fields. In late spring new crops including cotton provide increased and fresh habitat for insect access, dissipating insect populations from native vegetation over summer. Thus native vegetation elements in intensive agricultural landscapes undergo extensive insect population fluctuations providing oscillating microbat foraging value.

A study of beneficial insects (Rencken *et al.* 2005), in a native vegetation windbreak adjacent to cotton fields upstream from the study area in spring found green lacewings (*Chrysopa* spp.), brown lacewings (*Micromus tasmaniae*), red and blue beetles (*Dicranolaius bellulus*), damsel bugs (*Nabis kinbergii*), and two ladybird species and their larvae, but in summer found only red and blue beetles and damsel bugs. In predominantly river red gum riverine trees, brown and green lacewings and red and blue beetles were present in spring, but only damsel bugs in summer. Since the industry-wide adoption of Integrated Pest Management (IPM) and Best Management Practice (BMP), all these predatory insect species have been found in cotton crops during spring and summer. Little research has investigated insect pest species and native vegetation relationships in cotton landscapes. However a recent presentation of preliminary spring research results investigating both pest and beneficial insects to cotton in native vegetation and adjoining crops (Bianchi 2008), found with some exceptions beneficial insects reproducing and more abundant in native vegetation, compared to pests reproducing and more abundant in crops. Bianchi's research results will be significant for a greater understanding of reasons for microbat movement across cotton landscapes.

6.7.4 CONCLUSION

The seasonal distribution patterns of call and feeding buzz abundance examined in this chapter have begun to reveal the seasonal movement of microbat foraging activity across a cotton production landscape. Seasonal depletions of available prey resources in one element of the total agricultural landscape, result in shifts of microbat foraging activity to alternate elements of the landscape in search of prey.

As microbat foraging activity is dependant upon insect prey supply much of microbat activity is dependant upon management practices in these agricultural landscapes. Allmost all landscape elements have some form of management practice imposition that ultimately affects insect populations and therefore microbat foraging habitat. These practices include grazing, supplementary feeding and associated seasonal stock movements within native vegetaton remnants, preparation for crops, management of insect and plant pests both chemical and tilling, fertilising, irrigating, and picking and harvesting of crops. Because of their extent in these agricultural landscapes the intensive management elements have now been incorporated into microbat foraging habitat

The presence and distribution of microbats shown by this study has provided evidence that microbats are contributing an ecosystem service to cotton production by their associated mitigation of insect pest populations. An interrelationship is thereby evident. It is therefore imperative that the cotton industry and other agricultural industries recogise microbat contribution to IPM and manage for microbat sustainability. To continue providing important IPM ecosystem services to agricultural enterprises, a diversity of both native vegetation foraging and tree hollow roosting habitats must be maintained to ensure the sustainability of microbat communities in these landscapes.

It is also imperative to recognise that agricultural landscapes are still providing habitat for communities of microbats, even though these habitats have been very much altered. Extensive studies are required to monitor changes in abundance and diversity.

CHAPTER 6.7 MICROBATS AND VEGETATION ACROSS THE LANDSCAPE
PART B SPECIES DISTRIBUTION – SEASONAL COMPARISON

6.7.5 SPECIES IN THE NATURAL LANDSCAPE

This section compares the same sampling effort across seasons and landscape distribution for individual species within guildes. Guild structure is based on many factors structured around ultrasound frequencies. In the text and tables combining guilds, the lowest frequency is first or at the top, and the highest last or at the bottom. Individual guild tables are ordered with the lowest frequency at the bottom of the table.

Presence/absence

A seasonal comparison of the presence and absence of species within guilds for the seven native vegetation landscape categories is set out in Table 6.7f. For each species, the last column identifies the number of native vegetation landscape categories present for each season, from which a total percentage presence was calculated.

Guild 2 recorded the overall highest percentage presence (77%), across the three seasonal surveys. Very similar but lower presence percentages were recorded for the three other guilds: Guild 1 (45%), Guild 3 (41%), and Guild 4 (46%).

Table 6.7.f. A seasonal comparison of presence/absence for Guilds and species at native vegetation landscape categories
(Species ordered according to ultrasound frequencies – lowest to highest)

Guilds & species	Native vegetation landscape categories																					Pres. Land. Cat. sp,su.au
	A rgf			B rgow			C pb			D gb			E mix			F cp			G git			
	sp	su	au	sp	su	au	sp	su	au	sp	su	au	sp	su	au	sp	su	au	sp	su	au	
Guild 1																						Total 7
T.a.			P	P		P							P		P	P		P				3,0,4
S.f.	P	P	P	P	P	P	P	P	P				P	P	P		P			P		4,6,4
Guild 2																						
*M.*sp.4		P		P	P	P	P	P	P	P			P	P	P			P	P		P	5,4,5
C.g	P	P	P	P	P	P	P	P	P	P	P		P	P	P		P	P		P		5,7,5
Unid	P		P	P		P		P	P			P	P		P			P	P		P	4,1,7
*M.*sp.2	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	7,7,7
*M.*sp.3	P	P	P	P	P	P	P	P	P	P		P	P	P		P	P		P			7,5,4
S.b.	P	P	P	P	P	P	P	P	P	P	P		P	P	P	P	P	P		P		6,7,5
Guild 3																						
S.g.	P	P		P	P	P	P	P	P	P	P		P	P	P	P	P		P	P		7,7,3
C.p.		P		P		P	P	P	P		P			P	P			P			P	2,4,5
V.d.								P	P													0,1,1
V.r.				P																		1,0,0,
V.v.	P		P	P			P	P	P	P		P	P		P	P	P	P			P	6,2,5
Guild 4																						
C.m.	P	P	P	P	P	P		P	P			P	P	P	P		P	P				3,5,6
V.t.	P			P											P							2,0,1
*N.*spp	P	P	P		P	P	P		P		P		P		P			P	P			4,3,5
TOT	11	10	10	14	9	12	10	12	13	7	6	5	12	9	13	6	8	10	6	5	5	

KEY:
Native vegetation landscape categories: (Argf) river gum forest; (Brgow) river gum open woodland; (Cpb) poplar box; (Dgb) grey box; (Emix) mixed (Fcp) cypress pine); (Git) grasslands and isolated trees.
Presence/absence: (P yellow) present; **Seasonal surveys**: (sp) spring; (su) summer; (au) autumn.
Species: Guild 1: (*T.a.*) *Tadarida australis*; (*S. f.*) *Saccolaimus flaviventris*;
Guild 2: (*M.* sp. 4) *Mormopterus* spp. 4; (*C. g.*) *Chalinolobus gouldii*; (*M.* sp.2) *Mormopterus* spp. 2; (*M.* sp.3) *Mormopterus* species 3; (*S. b.) Scotorepens balstoni*;
Guild 3: (*S. g.*) *Scotorepens greyii*; (*C.p.*) *Chalinolobus picatus*; (*V. d.*) *Vespadelus darlingtoni*; (*V. r.*) *Vespadelus regulus*; (*V. v.*) *Vespadelus vulturnus*;
Guild 4: (*C. m.*) *Chalinolobus morio*; (*V. t.*) *Vespadelus troughtoni*; (*Ny.* spp.) *Nyctophilus* spp.
Species richness: (red) highest richness; (orange) second in richness;

The individual species that recorded highest percentage presence across three seasons at total native vegetation landscape categories were predominantly Guild 2 species: *Mormoterus* sp. 2 (100%), *Scotorepens balstoni* (86%), *Chalinolobus gouldii* and *Scotorepens greyii* (both 80%), *Mormopterus* sp. 3 (76%), *Saccolaimus flaviventris* and *Mormopterus* sp. 4 (both 66%). The two species not in Guild 2 use frequencies immediately adjacent those utilised by Guild 2 species: *S. flaviventris* (higher) and *S. greyii* (lower). The remaining Guild 2 "group of unidentified calls" recorded a 57% presence.

Chalinolobus morio, Vespadelus vulturnus in Guild 3 and *Nyctophilus* spp. in Guild 4 recorded 67%, 66% and 57% presence respectively and *Chalinolobus picatus* (Guild 3) recorded 52%. Due to the seasonal absence the remaining species all recorded much lower percentage presence. *Tadarida australis* (Guild 1) and *Vespadelus troughtoni* (Guild 4), both absent in summer, recorded 19% and 14% presence respectively; and *Vespadelus darlingtoni* (Guild 3), absent in spring, recorded 9.5% presence; *Vespadelus regulus* (Guild 3), absent in summer and autumn, recorded 4.8%.

Species richness

The landscape categories that recorded the highest seasonal species richness (Table 6.7f) were Brgow in spring (14), Cpb and Emix in autumn (both 13), and Emix in spring, Cpb in summer, and Brgow in autumn (all 12), with lowest richness for Git in summer ant autumn, and Dgb in autumn. Highest overall species richness was recorded for Brgow, Cpb and Emix, and the lowest for Git and Dgb. Although adjustment for sample effort ordered species richness from Dgb, to Argf, Fcp, Emix, and Cpb, due to the proportional representation of landscape categories in the study area adjustment for sample effort in this instance is not indicative of species landscape utilisation.

Seasonal patterns - Guilds, species, call and feeding buzz abundance

Figs. 6.7i.a, i.b, ii.a, ii.b, iii.a & iii.b in Attachment 6.7Bi define the seasonal distribution of microbat total call abundance (mtca), and microbat total feeding buzz abundance (mtfba), for individual species within Guilds, across the seven native vegetation landscape categories. The same sample effort, representative of the percentage in the study area for each category, is replicated across seasons.

Guild 1 – frequencies outside insect hearing capabilities

The seasonal distribution of total call abundance for the two species within Guild 1 is summarised in Table 6.7g. For both Guild 1 species call abundance was highest in autumn, whereas feeding buzz abundance was highest in summer for *Saccolaimus flaviventris*, and in autumn for *Tadarida australis*.

Table 6.7.g. Seasonal distribution of mtca for species within Guild 1 across the seven native vegetation landscape categories. (Species ordered according to ultrasound frequencies – lowest to highest)

Species and season	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**
Saccolaimus flaviventris							
spring	3	**7**	4		**9**		
summer	2	**9**	6		2	**11**	1
autumn	1	**25**	**9**		2		
Tadarida australis							
spring		**4**			**2**	1	
summer							
autumn	5	**14**			**6**	1	

KEY:
Landscape categories: (Argf) river gum forest (5); (Brgow) river gum open woodland (11); (Cpb) poplar box (7); (Dgb) grey box (2); (Emix) mixed species (6); (Fcp) cypress pine (4); (Git) grasslands and isolated trees (4).
Seasonal results: (red & bold) highest; (bold) second highest.

Tadarida australis

With an absence in summer the most significant results were in autumn – rgow(14 calls, 4 buzzes), rgf (5 calls, 2 buzzes), mix (6 calls).

Saccolaimus flaviventris

Call abundance was highest in autumn, buzz abundance was highest in summer and both were lowest in spring. Highest call abundance although recorded in all seasons (7, 9, 25) for rgow seasonally shifted in spring from mix (9), to cp (11) in summer, to pb(9) in autumn. Highest feeding buzz abundance was recorded in spring for rgow(4), in summer for cp (9), and in autumn for rgow(5).

Guild 2 – frequencies within insect hearing capabilities

The seasonal distribution of total call abundance for individual species within Guild 2 is summarised in Table 6.7h. For Guild 2 species the highest total call abundance in spring was recorded by *Mormopterus* sp. 3 and *Scotorepens balstoni*, in summer by *Chalinolobus gouldii* and *Scotorepens balstoni* and in autumn by the "unidentified group of calls" and *Mormopterus* sp. 2. The highest total feeding buzz abundance in spring was recorded by *C. gouldii*, *Mormopterus* sp. 3, then *S. balstoni*, in summer by *C. gouldii*, and in autumn by the "unidentified group of calls".

Table 6.7.h. Seasonal distribution of mtca for species within Guild 2 across the seven native vegetation landscape categories.
(Species ordered according to ultrasound frequencies – highest to lowest)

Species and season	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**
Scotorepens balstoni							
spring	**16**	5	**36**	5	13	**6**	
summer	10	**32**	14	2	8	**16**	3
autumn	**3**	2	2		**3**	2	
Mormopterus **sp. 3**							
spring	**46**	4	7	**22**	8	2	3
summer	**17**	4	**16**		4	1	
autumn	**4**	**2**	1	1			
***Mormopterus* sp. 2**							
spring	5	**17**	7	3	**24**	1	8
summer	6	**15**	**10**	1	2	3	**10**
autumn	**8**	**24**	3		5	1	**8**
Unid calls							
spring	1	**7**			1		**2**
summer			**1**				
autumn	2	**97**	3	9	**13**	2	3
Chalinolobus gouldii							
spring	**33**	4	**29**	3	1		
summer	4	**26**	15	4	**25**	21	5
autumn	1	**5**	**5**	**7**		1	
***Mormopterus* sp. 4**							
spring		**1**	**2**	**1**	**2**		**1**
summer	1	**5**	**2**		1		
autumn	**6**		1	1		1	**5**

KEY:
Landscape categories: (Argf) river gum forest (5); (Brgow) river gum open woodland (11); (Cpb) poplar box (7); (Dgb) grey box (2); (Emix) mixed species (6); (Fcp) cypress pine (4); (Git) grasslands and isolated trees (4).
Seasonal results: (red & bold) highest; (bold) second highest.

Mormopterus sp. 4

Although low both total call and total buzz abundance were highest in autumn and lowest in spring. In spring, call abundance was highest for pb(2) and mix(2), in summer for rgow(5) and pb(2), and in autumn for rgow(6) and git(5). In spring there were no feeding buzzes recorded, in summer one buzz each was recorded for rgf, rgow and pb and in autumn two buzzes for git and one for rgow.

Chalinolobus gouldii

Call abundance was highest in summer, buzz abundance was highest in spring, and both were lowest in autumn. Although always recorded in pb the high call abundance recorded in spring for rgf(33) and pb(29), shifted in summer to rgow(26), mix(25), cp(21) and pb(15), and in autumn although much reduced shifted to mix(7), rgow(5) and pb(5). Highest feeding buzz abundance recorded in spring for pb(41) and rgf(38), shifted in summer to cp(16), rgow(15) and mix(12). The highest of the low autumn buzz abundance was for pb(3). For this species a single call in spring was very often long and included more than one feeding buzz.

"Unidentified group of calls"

Due to the difference in call structure and seasonal pattern these calls have been separated. They could be extreme seasonal variations of either *C. gouldii* or *Mormopterus*. sp 2 calls. Both call and feeding buzz abundance were highest in autumn, and lowest in summer. The low call abundance in spring concentrated in rgow(7), diminished to only one call in summer for pb, but in autumn extreme call abundance was recorded for rgow (97), mix(13) and gb(9). Although there was only one feeding buzz in spring and summer, the autumn calls were accompanied by buzzes – rgow (10 buzzes to 97 calls), mix (3 buzzes to 13 calls), and pb (1 buzz to the three calls).

Mormopterus species 2

Both call and buzz abundance were highest in spring and lowest in autumn. In spring and summer call abundance was recorded across all categories, and in autumn across six categories. Although activity levels were high for rgow across all seasons, the spring call abundance concentrated in mix(24) and rgow(17), changed in summer to a concentration in rgow(15), pb(10) and git(10) and again in autumn to rgow(24) and mix(13). A concentration of buzz abundance was recorded in spring for pb(7) and mix(5), in summer for two different categories rgow(8) and git(7) and in autumn for rgow(3) and mix(3).

Mormopterus species 3

Both call and feeding buzz abundance were highest in spring and lowest in autumn. Although the highest call abundance across all seasons was recorded for rgf(46, 17, 4), high call abundance was also recorded for gb(22) in spring and pb(16) in summer. Highest buzz abundance was similarly recorded in rgf(45) and gb(16) in spring, and in summer for rgf(2) and pb(2). Buzz abundance was recorded across six categories in spring and five in summer, with only one buzz for two categories in autumn.

Scotorepens balstoni

Call abundance was highest in summer, feeding buzz abundance highest in spring and both were lowest in autumn. The high concentration of spring calls in pb(36), rgf(16) and mix(13), shifted in summer to rgow(32), cp(16) and pb(14), and in autumn reduced calls fairly evenly spread across five categories the highest rgf(3) and mix(3). The feeding buzz to call ratio was extremely high in spring, particularly for pb where 36 calls contained 47 feeding buzzes, but also for rgf where 16 calls contained ten feeding buzzes. In summer the feeding buzz to call ratio was low with 6 buzzes for 32 calls recorded for rgow, and 3 buzzes each to 16, 14, 10 and 8 calls, for cp, pb, rgf and mix respectively. In autumn one buzz was recorded to 3, 2 and 2 calls, for mix, pb, cp respectively.

Guild 3 – frequencies within insect hearing capabilities

The seasonal distribution of total call abundance for individual species within Guild 3 is summarised in Table 6.7i. Seasonal absence was recorded for two species: *Vespadelus darlingtoni* in spring and *Vespadelus regulus* in summer and autumn. The highest call abundance as well as highest feeding buzz abundance was recorded for *Scotorepens greyii* in summer and spring, followed by *Vespadelus vulturnus* in autumn.

Table 6.7.i. Seasonal distribution of mtca for species within Guild 3 across the seven native vegetation landscape categories.
(Species ordered according to ultrasound frequencies – highest to lowest)

Species & season	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**
Vespadelus vulturnus							
spring	**2**	1	1	**4**	1		
summer	**3**					**2**	
autumn	**4**		3	2	2	**7**	1
Vespadelus darlingtoni							
spring							
summer			**1**				
autumn			**1**				
Vespadelus regulus							
spring		**2**					
summer							
autumn							
Chalinolobus picatus							
spring		**1**	**1**				
summer	**3**		**2**	1	**2**		
autumn		**x**	**3**		**x**	**x**	**x**
Scotorepens greyii							
spring	4	1	**6**	2	**13**	3	3
summer	**7**	3	**7**	2	**15**	**7**	2
autumn		1	**8**		**2**		

KEY:
Landscape categories: (Argf) river gum forest (5); (Brgow) river gum open woodland (11); (Cpb) poplar box (7); (Dgb) grey box (2); (Emix) mixed species (6); (Fcp) cypress pine (4); (Git) grasslands and isolated trees (4).
Seasonal results: (red & bold) highest; (bold) second highest.

Scotorepens greyii

Both call abundance and feeding buzz abundance were highest in summer and lowest in autumn. The spring concentration of call abundance in mix and pb extended in summer from mix and pb, to rgf and cp, but in autumn dimished to pb. Although the highest overall buzz abundance was recorded in summer, the highest buzz abundance in spring as well as summer was for mix (13 buzzes to 13 calls) and (11/15) respectively. Other spring results included cp(4/3), and pb(2/6), and in summer rgow (3/3), cp (4/7), pb (2/7), and rgf (2/2).

Chalinolobus picatus

There was relatively even distribution of low total call abundance in summer and autumn, the lowest in spring. In spring one call was recorded for both rgow and pb, in summer rgf (3 calls), mix (4 buzzes/2 calls), pb (2 calls), and gb (1 buzz/1call), and in autumn pb (3 calls), mix (1 buzz/1 call), and 1 call each for git, rgow and cp.

Vespadelus regulus

This species was present only in spring, recording two calls for rgow. No feeding buzzes were recorded.

Vespadelus darlingtoni

This species was present in summer and autumn recording one call for each season in pb. No feeding buzzes were recorded.

Vespadelus vultunus

Both total call abundance and feeding buzz abundance were highest in autumn, but call abundance was lowest in summer and buzz abundance lowest in spring. A spring concentration of calls in gb(4), changed in summer to pb(3), and in autumn to cp(7) and rgf(4). Even though call abundance and buzz abundance were low, the feeding buzz to call ratio was extremely high: in autumn for cp (10 buzzes to 7 calls), for rgf (2/4), pb (3/3) and bg (2/2).

Guild 4 – utilising frequencies predominantly outside insect hearing capabilities.

The seasonal distribution of total call abundance for individual species within Guild 4 is summarised in Table 6.7j. The highest call abundance was recorded in spring for *Chalinolobus morio*. The highest feeding buzz abundance was recorded in autumn for *Nyctophilus* spp., then *C. morio*. *Vespadelus troughtoni* was absent in summer.

Chalinolobus morio

Highest total call abundance was in spring, the lowest in summer whereas highest total buzz abundance was in autumn, the lowest in spring and summer. The call abundance for spring concentrated in rgf (19), shifted in summer to mix(4) and pb (2) but returned in autumn to a low abundance in rgf(5) and gb(4), rgow (3). The 19 calls for rgf in spring contained 4 buzzes and in autumn 4 calls in gb contained 3 buzzes.

Vespadelus troughtoni

Absent in summer, the highest call abundance was in spring recorded for rgf (7); one call was recorded in spring and autumn for rgow. No feeding buzzes were recorded.

Table 6.7.j. Seasonal distribution of mtca for species within Guild 4 across the seven native vegetation landscape categories.
(Species ordered according to ultrasound frequencies – highest to lowest)

Species & season	rgf	rgow	pb	gb	mix	cp	git
***Nyctophilus* spp.**							
spring	**2**		1		🟥 **3**		1
summer	🟥 **1**	🟥 **1**	🟥 **1**				
autumn	🟥 **3**	**2**	🟥 **3**		1	**2**	
Vespadelus troughtoni							
spring	🟥 **7**	**1**					
summer							
autumn		🟥 **2**					
Chalinolobus morio							
spring	🟥 **19**	**2**			1		
summer	1	1	**2**		🟥 **4**	**2**	
autumn	🟥 **5**	3	3	**4**	2	3	

KEY:
Landscape categories: (Argf) river gum forest (5); (Brgow) river gum open woodland (11); (Cpb) poplar box (7); (Dgb) grey box (2); (Emix) mixed species (6); (Fcp) cypress pine (4); (Git) grasslands and isolated trees (4).
Seasonal results: (red & bold) highest; (bold) second highest.

Nyctophilus spp.

Both call and buzz abundance were highest in autumn and lowest in summer. Three *Nyctophilus* species were captured in spring across cp and mix. However the calls of this taxa are very soft and usually short and therefore difficult to record, so total call abundance is probably not indicative of presence. As other prey location strategies are employed by these species, often only a buzz component is recorded, however because calls are short and consist of rapid broadband repetition a buzz is difficult to differentiate from a call.

A spring call abundance concentrated in mix(3) and recorded also for rgf and pb and git, decreased in summer to one call each for rgf, rgow and pb, but increased in autumn to rgf(3) and pb(3) and a presence across rgow, cp and mix. Highest buzz abundance was in autumn recorded across four categories rgf(3), and rgow, pb and cp (2 buzzes each), followed by spring with one buzz each recorded for mix and git.

6.7.6 SPECIES IN THE INTENSIVE FARMING LANDSCAPE

Presence/absence

A seasonal comparison of presence and absence of species within Guilds for the three intensive farming landscape categories is set out in Table 6.7k. For each species, the last column identifies the number of intensive farming landscape categories present for each season, from which a total percentage presence was calculated

Table 6.7.k. A seasonal comparison of presence/absence for Guilds and species at intensive management landscape categories. (Species ordered according to ultrasound frequencies – lowest to highest)

Guilds & species	**Intensive management landscape categories**									**Pres. Land. Cat. Sp,Su,A**
	H ic			**I ws**			**J dc**			
	sp	su	au	sp	su	au	sp	su	au	
Guild 1										
T.a.	P			P						1,1,0
S.f.	P	P	P		P	P	P	P	P	3,2,3
Guild 2										
*M.*sp.4	P	P	P	P		P	P		P	3,2,2
C.g	P	P	P		P	P	P	P	P	3,2,3
Unid	P		P			P			P	2,1,1
*M.*sp.2	P	P	P	P	P	P	P	P	P	**3,3,3**
*M.*sp.3	P	P		P	P	P			P	2,3,1
S.b.	P	P	P	P	P	P	P	P	P	**3,3,3**
Guild 3										
S.g.	P	P	P		P	P	P	P	P	3,2,3
C.p.					P		P		P	0,1,2
V.d.						P				0,1,0
V.r.										0,0,0
V.v.	P		P						P	2,0,1
Guild 4										
C.m.	P	P					P		P	2,0,2
V.t.										0,0,0
*N.*spp	P	P					P		P	2,0,2
TOT	**12**	**9**	8	5	7	**9**	**9**	5	**12**	

KEY:
Intensive management landscape categories: (Hic) irrigated cropping; (Iws) water storage; (Jdc) dryland cropping
Presence/absence (Yellow P) presence
SPECIES:
Guild 1: (*T.a.*) *Tadarida australis*; (*S. f.*) *Saccolaimus flaviventris*;
Guild 2: (*M.* sp. 4) *Mormopterus* sp. 4; (*C. g.*) *Chalinolobus gouldii*; (*M.* sp.2) *Mormopterus* sp. 2;
(*M.* sp.3) *Mormopterus* sp. 3; (S. b.) *Scotorepens balstoni*;
Guild 3: (*S. g.*) *Scotorepens greyii*; (*C.p.*) *Chalinolobus picatus*; (*V. d.*) *Vespadelus darlingtoni*; (*V. r.*) *Vespadelus regulus*;
(*V. v.*) *Vespadelus vulturnus*;
Guild 4: (*C. m.*) *Chalinolobus morio*; (*V. t.*) *Vespadelus troughtoni*; (*Ny.* spp.) *Nyctophilus* spp.
Species richness: (red) highest, (orange second highest)

Guild 2 recorded the highest total seasonal percentage presence (79%) across the three seasonal surveys. For other guilds the lower percentage presence in declining order were 55% for Guild 1, 33% for Guild 3 and 29% for Guild 4.

The individual species that recorded the highest seasonal percentage presence across the three seasons at total intensive farming categories were: 100% for both *Mormoperus* sp. 2 and *Scotorepens balstoni* in Guild 2, 88% for *Saccolaimus flaviventris* (Guild 1), *Chalinolobus gouldii* (Guild 2) and *Scotorepens greyii* (Guild 3), 77% for *Mormopterus* sp. 4 and 66% for *Mormopeorus* sp. 3 (both in Guild 2). The highest presence (100%), was recorded by two Guild 2 species, and between 88% and 66% presence was recorded by one Guild 1, three Guild 2 and one Guild 3 species.

The remaining species all recorded less than a 50% presence. A 44% presence was recorded for the "unidentified group of calls" (Guild 2), and *Chaliolobus morio* and

Nyctophilus spp. both in Guild 4, 33% presence for *Chalinolobus picatus* and *Vespadelus vulturnus* both in Guild 3, 22% presence for *Tadarida australis* (Guild 1), and 11% presence for *Vespadelus darlingtoni* (Guild 3). *Vespadelus regulus* (Guild 3) and *Vespadelus troughtoni* (Guild 4) were absent from these intensive management landscape categories.

Species richness

The landscape categories that recorded the highest seasonal species richness (Table 6.7k) were Hic in spring and Jdc in autumn (each 12 species), followed by Hic in summer, Iws in autumn, and Jdc in spring (all 9), with lowest richnest for Iws in spring and Jdc in summer. Highest overall species richness was recorded for Hic and lowest for Iws. Although adjustment for sample effort ordered species richnes from Iws to Jdc to Hic, due to the proportional representation of landscape categories in the study area adjustment for sample effort in this instance is not indicative of species landscape utilisation.

Seasonal patterns - Guilds, species, call and feeding buzz abundance

Figs. 6.7iv.a, iv.b, v.a, v.b, vi.a and vi.b (Attachment 6.7Bi), define the seasonal distribution of microbat total call abundance (mtca) and microbat total feeding buzz abundance (mtfba) for individual species within Guilds, across the three intensive farming landscape categories. The same sample effort, representative of the percentage in the study area for each category, is replicated across seasons.

Guild 1 – frequencies outside insect hearing capabilities

The seasonal distribution of call abundance for the two Guild 1 species is summarised in Table 6.7l. The highest total call abundance was recorded in autumn for *Saccolaimus flaviventris*.

Table 6.7.l. Seasonal distribution of mtca for species within Guild 1 across the three intensive management landscape categories. (Species ordered according to ultrasound frequencies – highest to lowest)

Species and season	ic	ws	dc
Saccolaimus flaviventris			
spring	**1**		**3**
summer	**3**	**2**	**2**
autumn	**5**	**3**	**3**
Tadarida australis			
spring	**1**	**1**	
summer			
autumn			

KEY
Landscape categories: (ic) irrigated cropping (16); (ws) water storage (4); (dc) dryland cropping (5)
Seasonal results: (red & bold) highest; (orange & bold) second highest.

Tadarida australis
Two calls only were recorded in spring, one each for ic and ws. No feeding buzzes were recorded.

Saccolaimus flaviventris
Total call abundance was highest in autumn lowest in spring. Although recorded for all categories with exception of ws in spring, the highest call abundance was for ic(5) in autumn. No feeding buzzes were recorded.

Guild 2 - frequencies within insect hearing capabilities
The seasonal distribution of total call abundance for individual species within Guild 2 is summarised in Table 6.7m.

Table 6.7.m. Seasonal distribution of mtca for species within Guild 2 across the three intensive management landscape categories.
(Species ordered according to ultrasound frequencies – highest to lowest)

Species and season	ic	ws	dc
Scotorepens balstoni			
spring	**14**	1	**2**
summer	**32**	**11**	7
autumn	1	**3**	**11**
***Mormopterus* sp. 3**			
spring	**20**	**1**	
summer	**5**	**1**	
autumn		**2**	**1**
***Mormopterus* sp. 2**			
spring	**27**	2	**5**
summer	**32**	1	**6**
autumn	**4**	**3**	2
Unidentified calls			
spring	**3**		
summer			
autumn	**2**	**3**	**3**
Chalinolobus gouldii			
spring	**19**		**1**
summer	**27**	**9**	**1**
autumn	**4**	**2**	**2**
Mormopterus sp. 4			
spring	**8**	1	**5**
summer	**8**		
autumn	**1**	**1**	**1**

KEY
Landscape categories: (ic) irrigated cropping (16); (ws) water storage (4); (dc) dryland cropping (5)
Seasonal results: (red & bold) highest; (orange & bold) second highest.

For Guild 2 species, the highest total call abundance was recorded in summer by *Scotorepens balstoni*, *Mormopterus* sp. 2 and *Chalinolobut gouldii*. The highest total feeding buzz abundance was recorded in spring by *M.* sp. 2, *Mormopterus* sp. 3 and *C. gouldii*. Although in spring and summer call abundance was concentrated in ic, in autumn call abundance for ic drastically declined, but except for *M.* sp 3 was still recorded. Call abundance was higher for dc than ws. Although feeding buzzes in spring were highest and recorded only for ic, in summer buzzes were recorded predominantly for ws.

Mormopterus species 4

Total call abundance was highest in spring, total feeding buzz abundance was highest in summer, with both lowest in autumn. Cotton fields were utilised in spring (8 calls) and summer (1 buzz to 8 calls) and dryland cropping in spring (5 calls). One call was recorded for ws in spring and one call each for ic, dc and ws in autumn. There were no feeding buzzes recorded for water storages or dryland cropping.

Chalinolobus gouldii

Total call abundance was highest in summer, total feeding buzz abundance highest in spring and both were lowest in autumn. Cotton fields were utilised in spring (14 buzzes to 19 calls) and summer (4/27), and water storages in summer (8/9). Calls were recorded in autumn for ic (4), ws (2) and dc(2), and one call for dc in spring and summer. No feeding buzzes were recorded for dc, or for ic or ws in autumn.

"Unidentified group of calls"

Low total call abundance was low but highest in autumn, and absent in summer. Calls were recorded over cotton fields in spring (3), and in autumn over water storages (3), dryland cropping (3) and cotton fields. No feeding buzzes were recorded.

Mormopterus species 2

Total call abundance was highest in summer, total feeding buzz abundance highest in spring, both lowest in autumn. Although calls were recorded for all three categories across all seasons, cotton fields were utilised extensively in both spring and summer, and dryland cropping fields move in spring and summer than autumn. Buzz and call abundance included: for cotton fields in spring (18 buzzes/27 calls), in summer (1/32), and in autumn (4 calls); for dryland cropping in spring (0/5), in summer (2/6), and in autumn (1/2); and for water storages in spring (0/2), in summer (1/1), and in autumn (0/2). Altogether for these farming categories, in spring 18 buzzes to 34 calls, in summer 4 buzzes to 40 calls, and in autumn 1 buzz to 8 calls were recorded.

Mormopterus species 3

Both total call and total feeding buzz abundance were highest in spring and lowest in autumn. Although cotton fields were utilised extensively in spring the reduced activity in summer included feeding buzzes. Buzz and call abundance included: for cotton fields in spring (15 buzzes/20 calls), and in summer (3/5); for water storages, in spring (0/1), in summer (1/2), and in autumn (0/2) and for dryland cropping in autumn (0/1). Altogether for these farming categories, 15 buzzes to 21 calls were recorded in spring, 5 buzzes to 6 calls in summer, and 1 buzz to 3 calls in autumn. No feeding buzzes were recorded over cotton fields in autumn.

Scotorepens balstoni

Both total call abundance and total feeding buzz abundance were highest in summer and lowest in autumn. Although all three landscape categories were utilised across all seasons, cotton fields and water storages were utilised more in summer, and dryland cropping more in autumn. Buzz and call abundance included for cotton fields: in spring (6 buzzes to 14 calls), in summer (4/32), and in autumn (0/1); for water storages in spring (0/1), but in summer (6/11), and in autumn (2 calls); for dryland cropping fields in spring (0/2), in summer, (1/7), and in autumn (6/11). For these farming categories 6 buzzes to 17 calls in spring, 11 buzzes to 50 calls in summer, and 6 buzzes to 14 calls in autumn were recorded.

Guild 3 - frequencies within insect hearing capabilities

The seasonal distribution of total call abundance for individual species within Guild 3 is summarised in Table 6.7n. For Guild 3 species the highest total call abundance was recorded by *Scotorepens greyii* in summer, *Vespadelus vulturnus* in autumn and *S. greyii* in spring and *V. darlingtoni* in autumn. Only *V. vulturnus*, and *S. greyii* utilised cotton fields and no *V. regulus* calls were recorded for these categories.

Scotorepens greyii

Total call abundance was highest in summer, total feeding buzz abundance highest in spring and both were lowest in autumn. Buzz and call abundance included: for cotton fields in spring (5 buzzes/7 calls), in summer (1/9) and in autumn (0/2), for water storages, in summer (1/2) and in autumn (0/3), for dryland cropping fields in spring (0/1), in summer (1/ 3) and in autumn (0/1).

Table 6.7.n. Seasonal distribution of mtca for species within Guild 3 across the three intensive management landscape categories.
(Species ordered according to ultrasound frequencies – highest to lowest)

Species and season	**ic**	**ws**	**dc**
Vespadelus vulturnus			
spring	**2**		
summer			
autumn	**3**		**1**
Vespadelus darlingtoni			
spring			
summer			
autumn			**7**
Vespadelus regulus			
spring			
summer			
autumn			
Chalinolobus picatus			
spring			**1**
summer		**2**	
autumn			**1**
Scotorepens greyii			
spring	**7**		**1**
summer	**9**	2	**3**
autumn	**2**	**4**	1

KEY
Landscape categories: (ic) irrigated cropping (16); (ws) water storage (4); (dc) dryland cropping (5)
Seasonal results: (red & bold) highest; (orange & bold) second highest.

Chalinolobus picatus

Two calls were recorded in summer over water storages, and one call in both spring and autumn over dryland cropping. No feeding buzzes were recorded and no activity was recorded over cotton fields.

Vespadelus regulus No calls or buzzes were recorded for these farming categories.

Vespadelus darlingtoni

Seven calls were recorded in autumn over water storages, but no feeding buzzes.

Vespadelus vulturnus

Both total call abundance and total feeding buzz abundance were highest in autumn and absent in summer. Buzz and call abundance included: for cotton fields in spring (2 buzzes/2 calls), and in autumn (2/3), for dryland cropping fields in autumn (1/9). No calls were recorded for water storages.

Guild 4 - frequencies outside insect hearing capabilities

The seasonal distribution of total call abundance for individual species within Guild 4 is summarised in 6.7o. Very few calls of Guild 4 species were recorded for the intensive farming landscape categories.

Chalinolobus morio

For these categories buzz and call abundance included: over cotton fields one buzz and one call in spring, one call in summer, and over dryland cropping fields one buzz and three calls in spring and four calls in autumn.

Vespadelus troughtoni
No calls or feeding buzzes were recorded for these landscape categories.

Table 6.7.o. Seasonal distribution of mtca for species within Guild 4 across the three intensive management landscape categories.
(Species ordered according to ultrasound frequencies – highest to lowest)

Species and season	ic	ws	dc
***Nyctophilus* spp.**			
spring	1		1
summer	1		
autumn			1
Vespedalus troughtoni			
spring			
summer			
autumn			
Chalinolobus morio			
spring	1		3
summer	1		
autumn			4

KEY
Landscape categories: (ic) irrigated cropping (16); (ws) water storage (4); (dc) dryland cropping (5)
Seasonal results: (red & bold) highest; (orange & bold) second highest.

Nyctophilus spp.
For these farming categories one call was recorded over cotton fields in both spring and summer and one buzz in spring, and over dryland cropping fields one call was recorded in both spring and autumn possibly passing through.

Cotton varieties

The seasonal distribution of total call abundance (mtca) and total feeding buzz (mtfba) for the guilds and species recorded at irrigated cropping (ic) sites are set out in Table 6.7p. The sites are separated into three groups: (i) two-gene Bt Boldgard II™ cotton varieties; (ii) Conventional cotton varieties, and (iii) fallow fields. This sample effort reflects the Gm, Conventional and fallow cotton field status representation in the study area during the season of research. The sites within these categories have been ordered according to their adjacent category. Species have been separated into Guilds and the calls grouped by colour for number of calls, (red) 15+, (orange) 8-14, (yellow) 4-7, and (blank) <4.

Guilds

Guild 1 species: were recorded in spring at two Conventional sites (one mid cotton fields, one adjacent to rgow), in summer at one Conventional site (adjacent to fallow) and one

Bolgard II™ site (adjacent to fallow/cotton) and in autumn after cotton had been picked at four sites - one Bolgard II™, two Conventional and the fallow sites.

Guild 2 species: the Guild of greatest representation, were recorded at all 16 sites in all seasons with the exception two in spring, Bolgard II™ site (Eo), and the fallow site (Ao). Guild 3 species: were recorded in spring at two Bolgard II™ sites (adjacent to fallow, or a roadway and dead tree), and four Conventional sites (mid cotton fields, or adjacent to fallow, pb or rgow/water). In summer Guild 3 species were recorded at one Bolgard II™ site (adjacent to fallow/cotton) and four Conventional sites (one mid cotton fields, the others adjacent to pb, rgow/water or fallow). Only two of these sites were repeated, Hh adjacent to pb, and Em adjacent to rgow/water.

Table 6.7.p. Seasonal correlations, Hic (irrigated cropping) sites, cotton varieties, guilds and species, and microbat total call abundance (mtca) and microbat total feeding buzz abundance (mtfba) (Species ordered according to ultrasound frequencies – lowest to highest)

Cotton Variety & site	**Adjacent Category**	**mtca**	**mtfba**	**Spring species**	**mtca**	**mtfba**	**Summer species**	**mtca**	**mtfba**	**Autumn species**
Bolgard II™										
Hf	mid cotton/ Conventional	**1**	**0**	G.2: *M4*	**14**	**1**	G.2: *Cg*,*M2*,*M3*,***Sb*** G.4: *Cm*	**3**	**0**	G.2: *Cg*
En	fallow/cotton	**1**	**0**	G.2: *Cg*	**6**	**1**	G.1: *Sf* G.2: *M4*,*Cg* G.3: *Sg*	**2**	**1**	G.3: *Vv*
Ee	fallow	**8**	**4**	G.2: *M4*,***Cg***,*M2*,*Sb* G.3: *Sg*	**4**	**4**	G.2: *M2*,*Sb*	**1**	**2**	G.1: *Sf*
Eo	roadway/dead tree	**3**	**3**	G.3: *Sg*,*Vv*	**0**	**0**		**1**	**0**	G.2: *Sb*
Conventional										
Ha	mid cotton	**0**	**0**		**2**	**1**	G.2: *Cg*,*M2*	**3**	**0**	G.2: *M2*
Hd	mid cotton	**2**	**2**	G.2: *Cg*,*M2*	**17**	**0**	G.2:*M4*,***Cg***,***M2***,*M3*,***Sb*** G.3: *Sg*	**0**	**0**	
Hb	mid cot/Ingard	**18**	**11**	G.1:*Sf* G.2: *M4*,***Cg***,**un**,***M2***, *M3*,***Sb*** G.3: *Sg*	**1**	**0**	G.2: *M2*	**1**	**1**	?
Ak	Cpb&water chan.	**15**	**2**	G.2: *Cg*,*M2*:***M3***,*Sb*	**9**	**8**	G.2: *Cg*,*M2*,*Sb*	**2**	**0**	G.2: unid
Hh	Cpb	**3**	**1**	G.2: *M2*; G.3: *Sg*	**5**	**2**	G.2: *M4*,***M2*** G.3: ***Sg***	**2**	**0**	G.1: *Sf* G.2: *Cg*
Em	Brgow&water	**19**	**17**	G.2: *Cg*,***M2***,***M3***,*Sb* G.3: *Sg*	**29**	**3**	G.2: *Cg*,***M2***,*M3*,***Sb*** G.3: *Sg* G.4: *N*.sp	**0**	**0**	
Ec	Brgow	**5**	**1**	G.1:*Ta* G.2: *Cg*,*Sb*	**10**	**1**	G.2: *M4*,*Cg*,*M2*,*M3*,*Sb* G.3: *Sg*	**0**	**0**	
He	isolated field/ Git/W	**3**	**1**	G.2: *M2*,*Sb* G.4: *N*.sp	**5**	**0**	G.2: *Cg*,*M2*,*Sb*	**3**	**0**	G.2: *M4*,unid G.3: *Vv*
Eh	fallow	**23**	**20**	G.2: *M4*,***Cg***,***M2***,*Sb* G.3: *Sg* G.4: *Cm*	**11**	**6**	G.1: *Sf* G.2: ***Cg***,*M2*,*Sb*	**4**	**1**	G.2: *Cg*
Bk	fallow	**3**	**0**	G.2: *M2*	**4**	**0**	G.2: *M4*,*M2*	**2**	**2**	G.1: *Sf* G.2: *Cg*
Aq	fallow	**1**	**0**	G.2: *M4*	**8**	**0**	G.2: ***Cg***,*Sb*, G.3: *Sg*	**0**	**0**	
Fallow										
Ao	fallow	**0**	**0**		**7**	**2**	G.2: *Cg*,***M2***,*Sb*	**3**	**1**	G.1: *Sf* G.2: *M2*

KEY: (blank) <4; (Yellow) 4-7; (Orange) 8-14; (Red) 15+

Species:

Guild 1: (Ta) *Tadarida australis*; (Sf) *Saccolaimus flaviventris*;

Guild 2: *(M4) Mormopterus* sp. 4; (Cg) *Chalinolobus gouldii*; (unid) unidentified calls; (M2) *Mormopterus* sp. 2; (M3) *Mormopterus* sp. 3; (Sb) *Scotorepens balstoni*;

Guild 3: (Sg) *Scotorepens greyii*; (Cp) *Chalinolobus picatus*; (V d) *Vespadelus darlingtoni*; (Vr) *Vespadelus regulus*; (Vv) *Vespadelus vulturnus*;

Guild 4: (C m) *Chalinolobus morio*; (V t) *Vespadelus troughtoni*; (Nsp.) *Nyctophilus* spp.

Species bolded – major contributor to call numbers.

Guild 4 species: were recorded in spring at two Conventional sites, one of which was adjacent to grasslands/isolated trees, and in summer two sites, one Bolgard II™ mid cotton fields, and one Conventional adjacent to rgow/water.

Species

Of the Guild 1 species, *Tadarida australis* was recorded at the spring Conventional site adjacent to rgow, and *Saccolaimus flaviventris* recorded at four Conventional sites (one each in spring and summer and two in autumn), three Bolgard II™ sites (one each in summer and autumn), and the fallow site (in autumn).

The Guild 2 species recorded in spring were *Mormopterus* sp. 2 at 56% of sites (1B, 8C); *Chalinolobus gouldii* at 50% sites (2B, 6C); *Scotorepens balstoni* at 43% of sites (1B, 6C); *Mormopterus* sp. 4 at 31% ofsites (2B, 3C); *Mormopterus* sp. 3 at 18% of sites (C); and "unidentified calls" at one site (C). In summer the species recorded were *Mormopterus* sp. 2 at 81% of sites (2B, 9C, 1F); *C. gouldii* at 68% of sites (2B, 7C, 1F); *S. balstoni* at 62% of sites (1B, 7C, 1F); *Mormopterus* sp. 4 at 31% of sites (1B, 3C); and *Mormopterus s*p. 3 at 25% of sites (1B, 3C). In autumn the species recorded were *C. gouldii* at 25% of sites (1B, 3C); *Mormopterus* sp. 2 at 13% of sites (1C, 1F); *Mormoptorus* sp. 4 at one Conventional site; and *S. balstoni* at one Bolgard II™ site.

The Guild 3 species recorded were: in spring *Scotorepens greyii* at 37% of sites (2B, 4C) and *Vespadelus vulturnus* at one Bolgard II™ site; in summer *S. greyii* at 31% of sites (1B, 4C); and in autumn *V. vulturnus* at 13% of sites (1B, 1C).

The Guild 4 species recorded were: in spring *Nyctophilus* spp. and *Chalinolobus morio* at one Conventional site each; in summer *C. morio* at one Bolgard II™ site and *Nyctophilus* spp. at the Conventional site adjacent to rgow.

The species that recorded highest call abundance at sites of high levels of call abundance were *C. gouldii* (3 spring and 3 summer sites), *Mormopterus* sp. 2 (3 spring and 4 summer sites), *Mormopterus* sp. 3 (2 spring) and *S. balstoni* (1 spring and 2 summer sites) (Table 6.7o).

6.7.7 SPECIES IN THE CULTURAL LANDSCAPE.

Seasonal presence and landscape groupings

A comparison of the presence and absence of Guilds and species for the combined native vegetation and intensive management landscape categories is set out in Table 6.7q. For each species, the last column identifies the calculated total percentage presence from which a Guild percentage presence was calculated.

Table 6.7.q. A seasonal comparison of presence/absence for Guilds and species at the combined native vegetation and intensive management landscape categories (Species ordered according to ultrasound frequencies – lowest to highest)

Guilds and species	**Combined landscape categories**									**% presence**
	Native vegetation (total 7)			**Intense management (total 3)**			**Combined (total 10)**			
	sp	**su**	**au**	**sp**	**su**	**au**	**sp**	**su**	**au**	
Guild 1										
Tadarida australis	3	0	4	1	1	0	4	1	4	30%
Saccolaimus flaviventris	4	6	4	3	**2**	**3**	7	9	7	76%
Guild 2										
Mormopterus sp. 4	5	4	5	**3**	2	**2**	8	6	7	70%
Chalinolobus gouldii	5	**7**	5	3	**2**	**3**	8	**9**	8	83%
Unidentified calls)	4	1	7	2	1	1	6	2	**8**	53%
Mormopterus sp. 2	**7**	**7**	**7**	**3**	**3**	**3**	**10**	**10**	**10**	**100%**
Mormopterus sp. 3	7	5	4	2	3	1	9	**8**	5	73%
Scotorepens balstoni	6	**7**	5	**3**	**3**	**3**	9	**10**	8	90%
Guild 3										
Scotorepens greyii	**7**	**7**	3	3	**2**	**3**	10	**9**	6	83%
Chalinolobus picatus	2	4	5	0	1	2	2	5	7	46%
Vespadelus darlingtoni	0	1	1	0	0	1	0	1	2	10%
Vespadelus regulus	1	0	0	0	0	0	1	0	0	3%
Vespadelus vulturnus	6	2	5	2	0	1	9	2	6	56%
Guild 4										
Chalinolobus morio	3	5	6	2	0	2	5	5	8	60%
Vespadelus troughtoni	2	0	1	0	0	0	2	0	1	10%
Nyctophilus spp.	4	3	5	2	0	2	6	3	7	53%
Total	15	13	15	12	10	13	**15**	14	**15**	

KEY: (sp) spring; **(su)** summer; **(au)** autumn; **(red)** highest; **(bolded numbers)** maximum seasonal score.

The guild percentage presence results for the combined seasonal landscape categories in descending order were Guild 2 (78.1%), Guild 1 (53%), Guild 3 (40%) and Guild 4 (38%). These results varied from those for the separated native vegetation and intensive management categories. Guild 2 recorded highest presence for the combined and separated landscape categories with equal percentages for each category: combined categories (78.1%), native vegetation categories (78%) and intensive farming categories (78%). The percentage presence for the other Guilds varied. For the native vegetation categories all guilds recorded similar presence, in descending order Guild 1 (49%), Guild 4 (46%) slightly higher than Guild 3 (42%). For the intensive farming categories however the order varied and the differences were more acute - Guild 1 (55%), Guild 3 (33%) and Guild 4 (29%). Native vegetation and intensive management elements contributed different fractions of total call abundance for each guild, which in turn reflected the characteristics and parameters of the four guilds.

For individual species, the highest percentage presence across the combined native vegetation and intensive management categories were for: *Mormopterus* sp.2 (100%) *Scotorepens balstoni* (90%), *Chalinolobus gouldii* and *Scotorepens greyii* (both 83%), *Saccolaimus flaviventris* (76%), *Mormopterus* sp. 3 (73%) and *Mormopterus* sp. 4 (70%). Of the seven species recording 70% and greater presence, five were in Guild 2, one in Guild 4 and one in Guild 1. The Guild 1 (*S. flaviventris*) and Guild 4 species (*S. greyii*), use frequencies adjacent but slightly lower and higher than the Guild 2 frequency range.

For individual species the order, as well as the percentage presence for the combined landscape categories varied from the results for either native vegetation or intensive farming categories. Whereas *Mormopterus* sp. 2 recorded 100% presence for both native vegetation and intensive farming categories, *S. balstoni* recorded 100% presence for intense farming categories but 86% presence for the native vegetation categories resulting in 90% overall presence. On the other hand *C. gouldii* and *S. greyii* recorded 88% presence for intensive man categories and 80% for native vegetation categories resulting in 83% overall presence. For other species the order and the percentages differed between the native vegetation and intensive management categories. Although *S. flaviventris* also recorded 88% presence for intense management categories, a 66% presence for native vegegetation categories resulted in a 76% overall presence.

Species richness

Across the combined landscape categories a spring and autumn 15 species presence was recorded compared to 14 species in summer.

Seasonal call distribution and foraging patterns

This section combines the previously described seasonal distribution patterns for total call abundance and the known foraging patterns for individual species within guilds, to provide a greater understanding of the landscape utilisation as well as functional role for guilds and species across the study area landscape.

Guild 1 - frequencies outside insect hearing capabilities

For the species in Guild 1, the seasonal distribution of total call abundance across all ten landscape categories is set out in Table 6.7r. The known foraging patterns for Guild 1 species, illustrated in Fig. 6.7f, are above the canopy and open spaces (Chapter 6.6).

Tadarida australis

With a flight pattern of well above the canopy to the ground, although recorded in spring across five categories, highest call abundance in autumn was concentrated for river gum open woodlands, mixed species remants and river gum forest categories. Whilst not recorded in summer (Bullen & McKenzie 2005, pg. 103 above) this species was also not recorded in poplar box, grey box, grasslands and isolated tree, or dryland cropping categories in either spring or autumn, or irrigated cropping and water storages in autumn. Known prey include a predominance of moths, but also beetles, bugs, ants, grasshoppers and non-flying beetles (Chapter 6.6, Churchill 1998) some of which are cotton pests.

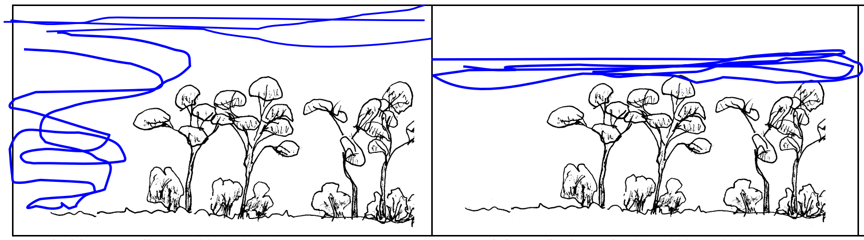
Table 6.7.r. Guild 1 Seasonal distribution of mtca for species across the seven native vegetation and three intensive management landscape categories. (Species ordered according to ultrasound frequencies – highest to lowest)

Guild 1	**Native vegetation landscape categories**								**Intensive man. land. categories**		
Season and species	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**		**ic**	**ws**	**dc**
Spring											
Saccolaimus flaviventris	3	**7**	**4**		**9**				1		3
Tadarida australis		**4**			**2**	**1**			**1**	**1**	
Summer											
Saccolaimus flaviventris	2	**9**	**6**		2	**11**	1		3	2	2
Tadarida australis											
Autumn											
Saccolaimus flaviventris	1	**25**	**9**		2				**5**	3	3
Tadarida australis	**5**	**14**			**6**	1					

KEY

Landscape categories: (rgf) river gum forest; (rgow) river gum open woodland; (pb) poplar box; (mix) mixed species; (cp) cypress pine; (git) grasslands and isolated trees; (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

Seasonal results: grouped (red & bold) highest; (orange & bold) second highest; (bold) third highest.



Known roost preference:
Tree hollows, cracks and overhangs

Tadarida australis (10kHz-13kHz) *Saccolaimus flaviventris* (17.5kHz-22kHz)

Fig. 6.7.f. Guild 1 species: Foraging patterns and roost preference

Saccolaimus flaviventris

With a flight pattern above the canopy, call abundance was concentrated in river gum open woodlands all seasons with the addition of poplar box in summer and autumn, mixed species remnants in spring, cypress pine in summer, irrigated cropping in summer and autumn, dryland cropping in spring and autumn and water storages in autumn. This species was not recorded in grey box any season, cypress pine or grasslands in spring and autumn, or water storages in spring. Known prey are predominantly beetles, but also bugs, ants and grasshoppers (Chapter 6.6, Churchill 1998).

The lack of recordings for these high flying species over some open space categories could be a reflection of the range limitations of recording equipment.

Guild 2 - frequencies within insect hearing capabilities

For the species in Guild 2 the seasonal distribution of total call abundance across all ten landscape categories is set out in Table 6.7s. The known foraging patterns for Guild 2 species, illustrated in Fig. 6.7g, are edges, open spaces or above the canopy (Chapter 6.6).

Mormopterus species 4

With a pattern of foraging amongst trees and to the ground, for this species low call abundance was recorded for irrigated cropping in spring and summer, dryland cropping in spring as well as river gum open woodlands in summer, and river gum forests and grasslands in autumn. Overall landscape utilisation included irrigated cropping and poplar box categories across all seasons, river gum open woodland and mixed species categories in spring and summer, dryland cropping categories in spring, grey box, grasslands and isolated tree and water storage categories in spring and autumn, river gum forest in summer and autumn. Known prey include a predominance of bugs many of which are agricultural pests**,** as well as beetles, ants and moths (Chapter 6.6, Churchill 1998).

Chalinolobus gouldii

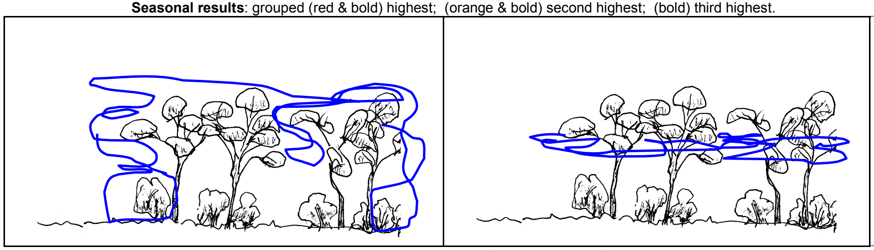
With pattern of foraging within the canopy or canopy gaps, very high call abundance was recorded in spring for river gum forest and poplar box as well as irrigated cropping categories in spring, in summer for irrigated cropping, river gum open woodland, mixed species, and (with reduced intensity) cypress pine and poplar box categories in summer. Overall landscape utilisation included irrigated cropping, river gum open woodland, poplar box, river gum forest, grey box and dryland cropping categories across all seasons, the mixed species category in spring and summer, cypress pine and water storages in summer and autumn, and the grasslands and isolated tree category in summer.

Table 6.7.s. Guild 2 Seasonal distribution of mtca for species across the seven native vegetation and three intensive management landscape categories. (Species ordered according to ultrasound frequencies – highest to lowest)

Guild 2	**Native vegetation landscape categories**							**Intensive manage. land. categories**		
Season and species	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**	**ic**	**ws**	**dc**
Spring										
Scotorepens balstoni	**16**	5	**36**	5	13	6		**14**	1	2
Mormopterus sp. 3	**46**	4	7	**22**	8	2	3	**20**	1	
Mormopterus sp. 2	5	**17**	7	3	**24**	1	8	**27**	2	5
Unidentified calls	1	**7**			1		**2**	**3**		
Chalinolobus gouldii	**33**	4	**29**	3	1			**19**		1
Mormopterus sp. 4		1	**2**	1	**2**		1	**8**	1	**5**
Summer										
Scotorepens balstoni	10	**32**	**14**	2	8	**16**	3	**32**	11	7
Mormopterus sp. 3	**17**	4	**16**	4		1		**5**	1	
Mormopterus sp. 2	6	**15**	**10**	1	2	3	**10**	**32**	1	6
Unidentified calls			**1**							
Chalinolobus gouldii	4	**26**	15	4	**25**	21	5	**27**	9	1
Mormopterus spp. 4	1	**5**	**2**		1			**8**		
Autumn										
Scotorepens balstoni	**3**	2	2		**3**	2		1	**3**	**11**
Mormopterus sp. 3	**4**	**2**	1	1					**3**	1
Mormopterus sp. 2	**8**	**24**	3		**5**	1	**8**	4	3	2
Unidentified calls	2	**97**	3	**9**	**13**	2	3	2	3	3
Chalinolobus gouldii	1	**5**	**5**	**7**		1		**4**	2	2
Mormopterus sp. 4	**6**		**1**	**1**		**1**	**5**	**1**	**1**	**1**

KEY Landscape categories: (rgf) river gum forest; (rgow) river gum open woodland; (pb) poplar box; (mix) mixed species; (cp)cypress pine; (git) grasslands and isolated trees; (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

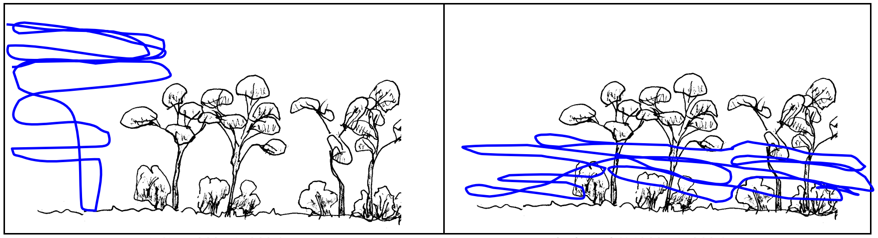
Seasonal results: grouped (red & bold) highest; (orange & bold) second highest; (bold) third highest.



Mormopterus sp. 4 (26kHz-29.5kHz)

Chalinolobus gouldii (27.5kHz-33kHz)

Unknown for *Mormopterus* sp. 2 (28.5kHz-31kHz)



Mormpoterus sp. 3 (34.5kHz-35kHz)

Scotorepens balstoni (29kHz-34kHz)

Known roost preference:
All tree hollows;
C. gouldii river red gum dead limbs;
M. sp. 2 tree spouts;
M. sp. 4 narrow entrances;
Others: roof cavities (*S. bal.*, *M.* sp. 3 & 4
M. sp. 3 water pipes & often with *S. bal.*

Fig. 6.7.g. Guild 2 species: Foraging patterns, and roost preferences

This species was not recorded at water storages or cypress pine in spring, grasslands sites in spring or autumn, or mixed species categories in autumn. This species was recorded present at 50% and 60% of irrigated cropping sites in spring and summer respectively, and provided a major component of calls at irrigated cropping sites with high call abundance in spring. In these open landscapes this species foraging habitat has extended to include open spaces. Known as an opportunist, and prey including a predominance of moths, but also bugs, beetles, flies, crickets, caterpillars, ants, stoneflies, cicadas, and leaf hoppers (Chapter 6.6, Churchill 1998) this species would appear to be a major predator of insects in cotton fields and contributor to pest insect management.

“Unidentified calls”
As this group of calls was not identified there is no known associated foraging pattern. Although almost entirely absent in summer, and absent from 50% of categories in spring, the predominantly autumn total call abundance for this group of calls across all categories was concentrated in river gum open woodlands. Calls were also recorded in spring for rgf, mix and git, in summer for pb, and in autumn mix, gb, as well as rgf, pb, cp and git. Because of the autumn dominance of these calls across all categories and the a very limited call abundance in autumn for *C. gouldii*, it would suggest these calls are in fact very altered seasonal call adaptations for *C. gouldii*.

Mormopterus species 2
The foraging pattern for this species is unknown. Although high call abundance was recorded in river gum open woodlands across all seasons, highest call abundance was recorded for irrigated ccropping in summer and spring, as well as mixed species in spring and poplar box in summer. The only absence recorded for this species was for poplar box in spring and grey box in autumn. This species recorded 56 % and 81% presence in spring and summer respectively at irrigated cotton sites and provided the second highest proportion of calls at the sites of high call abundance. With known prey to include bugs, ants, beetles and moths (Chapter 6.6, Churchill 1998) and a high recorded call abundance over cotton fields this species would appear to have been providing a major contribution to insect management over cotton fields.

Mormoptorus species 3
This species forages in unobstructed areas, including 3 to 5 meters above water. Although the very high spring call abundance was concentrated in river gum forest, it was also recorded for grey box and irrigated cropping categories. The summer high abundance while repeating the spring pattern included poplar box instead of grey box. This species was absent from only dryland cropping in spring and summer, grasslands in summer and autumn, grey box in summer, and cypress pine and irrigated cropping in

autumn. Although recorded present at only 18% and 25% of irrigated cropping sites in spring and summer, this species provided a major portion of call abundance at two cotton sites in spring of high call abundance. Both sites were adjacent to vegetation (poplar box and river gum open woodland) and water. Little is known of prey for this species but prey does include flies and ants (Chapter 6.6, Churchill 1998). This is another species that appears to have been contributing to pest insect management over cotton fields.

Scotorepens balstoni

With a foraging pattern that includes between trees, and also the ground, very high call abundance was concentrated in spring in poplar box, and to lesser extent river gum forest, irrigated cropping and mixed species categories. In summer high call abundance was concentrated in river gum open woodland and irrigated cropping categories, as well as poplar box, water storages and river gum forest, and the highest of the generally reduced autumn call abundance recorded for dryland cropping sites. This species was absent only from grasslands in spring and summer, and grey box in autumn. Although recorded at 43% and 62% of irrigated cropping sites in spring and summer respectively, call abundance from this species contributed only fourth highest of Guild 2 species to sites with high call abundance. Known however as an opportunist like many species in the study area, with prey including beetles, ants, bugs, moths, flies, grasshoppers, cockroaches, crickets, cicadas and non-flying insects (Chapter 6.6, Churchill 1998) this species would also appear to be contributing to pest insect management over and within cotton fields.

Guild 3 – frequencies within insect hearing capabilities

For the species within Guild 3 the seasonal distribution of total call abundance across all ten landscape categories is set out in Table 6.7t. The known foraging pattern for Guild 3 species, illustrated in Fig. 6.7h, is below the canopy and does not include open spaces (Chapter 6.6, Churchill 1998).

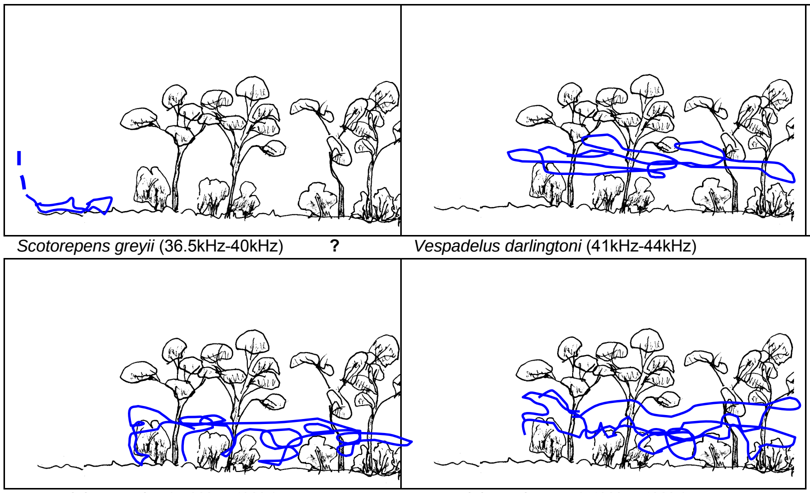
Table 6.7.t. Guild 3 - Seasonal distribution of mtca for species across the seven native vegetation and three intensive management landscape categories.

Guild 3	**Native vegetation landscape categories**							**Intensive manage. land. categories**		
Season & species	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**	**ic**	**ws**	**dc**
Spring										
Vespadelus vulturnus	**2**	**1**	**1**	**4**	**1**			**2**		
Vespadelus darlingtoni										
Vespadelus regulus		**2**								
Chalinolobus picatus		**1**	**1**							**1**
Scotorepens greyii	4	1	**6**	2	**13**	3	3	**7**		1
Summer										
Vespadelus vulturnus	**3**					**2**				
Vespadelus darlingtoni			**1**							
Vespadelus regulus										
Chalinolobus picatus	**3**		**2**	**1**	**2**				**2**	
Scotorepens greyii	**7**	3	**7**	2	**15**	**7**	2	**9**	2	3
Autumn										
Vespadelus vulturnus	**4**		**3**	2	2	**7**	**1**	**3**		1
Vespadelus darlingtoni			**1**							**7**
Vespadelus regulus										
Chalinolobus picatus		**1**	**3**		**2**	**1**	**1**			**1**
Scotorepens greyii		1	**8**		**2**			**2**	**4**	1

KEY

Landscape categories: (rgf) river gum forest; (rgow) river gum open woodland; (pb) poplar box; (mix) mixed species; (cp)cypress pine; (git) grasslands and isolated trees; (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

Seasonal results: grouped (red & bold) highest; (orange & bold) second highest; (bold) third highest.



Unknown for *Chalinolobus picatus* (42kHz-44kHz)

Scotorepens greyii (36.5kHz-40kHz) ? *Vespadelus darlingtoni* (41kHz-44kHz)

Known roost preference:
All tree hollows + buildings;
Others:
C. morio +bark, culverts, bridges;
C. picatus +caves, mines;
S. grey. + fence posts.

Vespadelus regulus (45kHz-46kHz) *Vespadelus vulturnus* (46kHz-49kHz)

Fig. 6.7.h. Guild 3 species: Foraging patterns and roost preference

Scotorepens greyii

Foraging patterns are unknown for this species, however known prey items have included many ground dwelling insects. Although call abundance was not overly high, the highest concentration was recorded for the mixed species remnants in both spring and summer, with reduced abundance recorded for poplar box across all seasons, irrigated cropping in spring and summer, river gum forest in summer, and water storages in autumn. This species was absent from only water storages in spring, river gum forest, grey box, cypress pine and grasslands categories in autumn, and was the only Guild 3 or 4 species to extensively utilise irrigated cropping categories. A presence of 38% at cotton sites in both spring and summer also provided a major portion of the high call abundance at a summer cotton site adjacent to poplar box. Known as an opportunist, with prey including non-flying ants, termites, crickets, leaf hoppers, bugs, beetles, flies and moths (Chapter 6.6, Churchill 1998) with an apparent foraging patterns including open spaces this species would also seem to be contributing to pest insect predation and management over and within cotton fields.

Chalinolobus picatus

The foraging pattern is unknown for this species. Very low call abundance was concentrated in river gum forests in summer and poplar box in autumn. Calls were recorded for poplar box in all seasons, river gum open woodland and dryland cropping in spring and autumn, mixed species in summer and autumn, river gum forests and water storages in summer, and cypress pine and grassland categories in autumn. Little is known of prey for this species but prey does include moths (Chapter 6.6, Churchill 1998).

Vespadelus regulus

The foraging pattern for this species is described as being at less than half the canopy height, in the understorey, within vegetation and on the ground. Call abundance was recorded in spring only in river gum open woodlands. This species was absent in summer and autumn. An opportunist, prey is known to include a predominance of moths, but also beetles, flies, bugs and ants (Chapter 6.6, Churchill 1998).

Vespadelus darlingtoni

Known to forage in the gaps between the canopy and the understorey and amongst trees, very low call abundance was concentrated in dryland cropping in autumn. In the study area many of the dryland cropping fields are edged with trees. Absent in spring the only other calls were recorded for poplar box in summer and autumn. Known prey include a predominance of moths, but also beetles, flies, bugs, spiders, termites, ants and lacewings (Chapter 6.6, Churchill 1998) many of which reside in remnant vegetation.

Vespadelus vulturnus

With foraging patterns described as below the canopy and between trees, and within the understorey 3 to 8 m from ground, low call abundance was concentrated in autumn in cypress pine and river gum forest, and grey box in spring. Whilst absence in autumn was recorded only for river gum open woodland and water storages, absences in spring included cypress pine, grasslands, dryland cropping and again water storages, and in summer calls for this species were only recorded for the most vegetated categories in the study area - river gum forest and cypress pine. Known as an opportunist, but of flying prey only, prey include a predominance of months, as well as flies, bugs, beetles, termites, spiders, grasshoppers, lacewings, ants, wasps and cockroaches (Chapter 6.6, Churchill 1998).

Guild 4 – frequencies outside insect hearing capabilities

For the species in Guild 4 the seasonal distribution of total call abundance across all ten landscape categories is set out in Table 6.7u. The known foraging pattern for Guild 4 species, illustrated in Fig. 6.7i, is below the canopy and does not include open spaces (Chapter 6.6).

Chalinolobus morio

Foraging patterns for this species include gaps between the canopy and the understorey and along forest trails. The highest concentration of call abundance was recorded in river gum forests in spring, with lower abundance for river gum forest and grey box in autumn, mixed species remnants in spring, and dryland cropping in spring and autumn. There was an bsence of calls for grasslands and water storages in all seasons, poplar box and cypress pine in spring, grey box in spring and summer, dryland cropping in summer, and irrigated cropping in autumn. The categories recording higher concentrations of call abundance were the least open vegetation communities in the study area with the exception of dryland cropping where fields are edged with native remnants. An opportunist, known prey include a predominance of moths, but also beetles, bugs, flies, ants, lacewings, wasps and termites (Chapter 6.6, Churchill 1998).

Vespadelus troughtoni

The foraging patterns are unknown for this species, as is its prey. Calls were recorded only for river gum forest in spring and summer, and river gum open woodland in spring, with the highest abundance in spring for river gum forest.

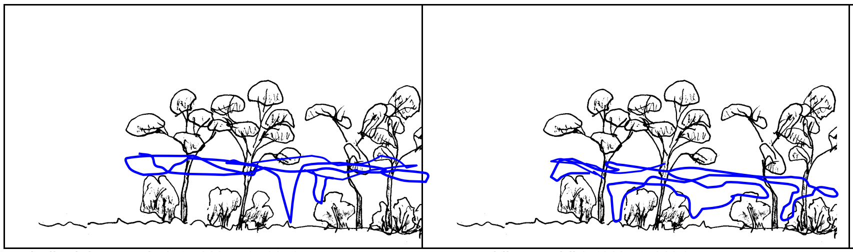
Table 6.7.u. Guild 4 - Seasonal distribution of mtca for species across the seven native vegetation and three intensive management landscape categories. (Species ordered according to ultrasound frequencies – highest to lowest)

Guild 4	**Native vegetation landscape categories**								**Intensive manag. land. categories**		
Season & species	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**		**ic**	**ws**	**dc**
Spring											
Nyctophilus spp.	**2**		**1**		**3**		**1**		**1**		**1**
Vespadelus troughtoni	**7**	**1**									
Chalinolobus morio	**19**	**2**			1				1		**3**
Summer											
Nyctophilus spp.	**1**	**1**	**1**						**1**		
Vespadelus troughtoni											
Chalinolobus morio	**1**	**1**	**2**		**4**	**2**			**1**		
Autumn											
Nyctophilus spp.	**3**	**2**	**3**		**1**	**2**					**1**
Vespadelus troughtoni		**2**									
Chalinolobus morio	**5**	**3**	**3**	**4**	2	**3**					**4**

KEY

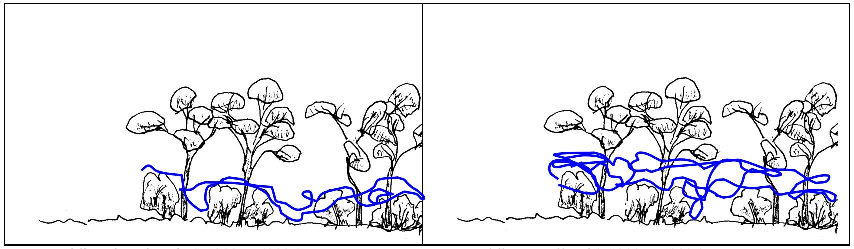
Landscape categories: (rgf) river gum forest; (rgow) river gum open woodland; (pb) poplar box; (mix) mixed species; (cp)cypress pine; (git) grasslands and isolated trees; (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

Seasonal results: grouped (red & bold) highest; (orange & bold) second highest; (bold) third highest.



Chalinolobus morio (48.5kHz-51.5khz) *Nyctophilus gouldi* (40kHz-67kHz)

Unknown for *Vespadelus troughtoni* (48kHz-55kHz)



Nyctophilus timoriensis (43kHz-71kHz) *Nyctophilus geoffroyi* (46kHz-66kHz)

Known roost preference*:*
C. morio *tree hollows, houses, bark, Fairy Martin nests, culverts, bridges;*
V. troug. *caves, boulder piles, mines, buildings;*
N. goul. *tree hollows, bark;*
N. tim. *tree hollows, fissures in dead limbs/trees, bark;*
N. geof. *fissures in dead trees, bark, buildings.*

Fig. 6.7.i. Guild 4 species: Foraging patterns and roost preference

Nyctophilus spp.

The three *Nyctophilus* species employ different foraging strategies. *N. gouldii* forages below the canopy, among trees and within vegetation and the understorey; *N. geoffroyi* forages in gaps between the canopy and understorey and the foraging pattern for *N. timoriensis* is from the understorey to the ground. These *Nyctophilus* spp. glean from vegetation and also utilise the ground as foraging habitat (Chapter 6.6, Churchill 1998).

The highest abundance for this taxa was recorded in mixed species remnants in spring and river gum forest and poplar box categories in autumn. Although call abundance was recorded at six spring categories, four summer, and six autumn categories, calls were absent from water storages and grey box sites all seasons, cypress pine in spring and summer, river gum open woodland in spring, mixed species and dryland cropping in summer, grasslands in summer and autumn, and irrigated cropping in autumn. As the calls of this taxa are very soft and they utilise other prey capture strategies such as passive listening and sight, call abundance is not indicative of either presence or landscape utilisiation. However because of slow and manourverable flight patterns these species do require more complex vegetation remnants with a shrubby understorey which is absent from much of the study area landscape. Known prey for these species varies between species however gleaning from the ground and vegetation are foraging strategies employed by most of these species. Although all are opportunists, for *Nyctophilus gouldi* prey include a predominance of moths, but also beetles, bugs, spiders, flies and ants; for *Nyctophilus timoriensis* non-flying insects, a predominance of caterpillars, but also scorpions and moths; and for *Nyctophilus geoffroyi* a predominance of moths together with spiders, non-flying ants, beetles, crickets, bugs, lacewings, flies, and cricket nymphs (Chapter 6.6, Churchill 1998). The Nycto geoff story at the commencement of this Thesis describes very clearly a role of this species in cotton production landscapes.

6.7.8 SITE PERCENTAGE PRESENCE

Seasonal distribution at landscape category sites

Previously in this chapter, total call abundance has been used as a measure of activity and distribution. The percentage presence at sites within individual landscape categories provides another interpretation of call abundance. For each season, site percentage presence related to sampling effort was plotted for each landscape category and, guilds (Fig. 6.7vii), species within Guilds 1, 3 and 4 (Fig. 6.7viii), and species within Guild 2 (Fig 6.7ix)(Attachment 6.7Bii). Groupings used were "guilds" for species, and "native vegetation" and "intensive farming" for landscape categories which were ordered in their proximity to the river.

In Fig. 6.7vii guild species representation varies from two (Guild 1), two & one taxa (Guild 4), five (Guild 3), and five and unknown calls (Guild 2). Except for Guild 2 all guilds include species that recorded seasonal absence. Guild 2 consistently recorded highest site percentage presence across all categories and seasons with one exception - a very low percentage presence for irrigated cropping sites in autumn. Guild 3 also recorded consistently high site percentage presence with some exceptions - lower presence at river gum open forest sites across all seasons, and low presence at dryland cropping sites in summer and irrigated cropping sites in autumn, and near absence at water storage sites in summer. Guild 1 recorded a generally lower overall site percentage presence as well as absences from grey box sites in all seasons, and grasslands and isolated trees in spring and summer. Guild 4 on the other hand not only consistently recorded lower site percentage presence and seasonal variation for all the native vegetation category sites, but also low presence at water storage and irrigated cropping sites in all seasons, grassland and isolated tree sites in summer and autumn, and cypress pine sites in summer.

In Fig. 6.7viii Guild 2 has been omitted due to the space and display constraints (displayed separately in Fig. 6.7ix). For Guilds 1, 3 and 4 the seasonal variation in site percentage presence and the distribution of presence for all species is clearly evident.

For Guild 1 species, *T. australis* was absent in summer, and the sites recording highest percentage presence and species richness for both species (Table 6.7v) were river gum open woodland and mixed species in spring and autumn, river gum forest in autumn and irrigated cropping in spring.

Table 6.7.v. Guild 1 species - Presence at percentage of sites
(Species ordered according to ultrasound frequencies – lowest to highest)

	rgf	rgow	pb	gb	mix	cp	git	ic	ws	dc
Spring	**S.f.**	🟥 T.a. **S.f.**	**S.f.**		🟥 T.a. **S.f.**	T.a.		🟥 T.a. S.f.	T.a.	S.f.
Summer	**S.f.**	**S.f.**	**S.f.**		**S.f.**	**S.f.**	**S.f.**	S.f.	S.f.	S.f.
Autumn	🟥 **T.a.** S.f.	🟥 **T.a.** **S.f.**	S.f.		🟥 **T.a.** **S.f.**	**T.a.**		**S.f.**	**S.f.**	**S.f.**

KEY:
Species: (T.a.) *Tadarida australis*; (S.f.) *Saccolaimus flaviventris*;
Landscape categories:
Native vegetation:(rgf) river gum forest; (rgow) river gum open woodland; (pb) poplar box; (gb) grey box;
(mix) mixed species; (cp) cypress pine;
Intensive management: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping.
(Red) Highest species richness; **(bolded)** High seasonal presence at percentage of sites

For Guild 3 species in spring and particularly in summer, *S. greyii* showed the highest site percentage presence across both native vegetation and intensive farming categories. In autumn however a high site percentage presence was recorded for all Guild 3 and Guild 4 species except *S. greyii*.

Generally for Guild 3 and 4 species, with the exception of dryland cropping sites in spring and autumn, the sites of least percentage presence were the intensive farming category sites across all seasons. Excluding *S. greyii*, low presence was also recorded for grey box sites in spring and autumn and cypress pine sites in spring, resulting in a low Guild 3 and 4 species richness for these sites (Table 6.7w).

Table 6.7.w. Guild 3 and 4 species – Presence at percentage of sites
(Species ordered according to ultrasound frequencies – highest to lowest)

	rgf	rgow	pb	gb	mix	cp	git	ic	ws	dc
Spring	S.g. V.v.	🟥 S.g. C.p. V.r. V.v.	**S.g.** **C.p.** V.v;	**S.g.** **V.v.**	**S.g.** V.v;	**S.g.** V.v.	**S.g**.	**S.g.** **V.v.**		S.g. C.p.
	C.m. V.t. N spp.	🟥 C.m. V.t.	N. spp		C.m. **N. spp.**		N, spp.	C.m. N.spp		C.m. N. spp.
Summer	**S.g.** **C.p**.	S.g.	**S.g**. C.p. V.d. **V.v.**	**S.g.** **C.p**	Sg. C.p.	**S.g.** V.v.	S.g.	**S.g.** **V.v.**	**S.g.** C.p.	S.g.
	C.m. N. spp.	C.m; N. spp.	C.m.	**N. spp**.	C.m.	**C.m.**		**C.m.** **N.spp.**		
Autumn	**V.v**.	S.g. C.p.	🟥 S.g. C.p. V.d. **V.v.**	**V.v.**	🟥 S.g. C.p. **V.v.**	C.p. **V.v.**	C.p. V.v.	S.g. V.v.	S.g. V.d.	S.g. C.p. V.v.
	C.m. N. spp.	C.m. N. spp.	🟥 **C.m.** **N.spp.**	**C.m.**	🟥 **C.m**. V.t. N. spp.	**C.m.** **N. spp.**				C.m. N.spp.

KEY
Species: **Guild 3**: (S.g.) *Scotorepens greyii*; (C.p.) *Chalinolobus picatus*; (V.r.) *Vespadelus regulus*;
(V.v.) *Vespadelus vulturnus*;
Guild 4: (C.m.) *Chalinolobus morio*; (V.t.) *Vespadelus troughtoni*.
Landscape categories:
Native vegetation:(rgf) river gum forest; (rgow) river gum open woodland; (pb) poplar box; (gb) grey box;
(mix) mixed species; (cp) cypress pine;
Intensive management: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping.
(Red) Highest species richness; **(bolded)** High seasonal presence at percentage of sites

In spring the lowest site percentage presence was recorded for *C. picatus*, *C. morio* and *V. darlingtoni*. In summer a pattern of overall reduced percentage presence for all Guild 3 and 4 species excluding *S. greyii*, also showed a concentration of that reduced presence at differing category sites for individual species. Those concentrations were: for *C. picatus* at grey box and river gum forest sites, for *V. darlingtoni* at poplar box sites, for *V. vulturnus* at cypress pine and poplar box sites, for *C. morio* at cypress pine, mixed species, poplar box and river gum forest sites, and for *Nytophilus* spp. at grey box and river gum forest sites. *V. regulus* and *V. troughtoni* were both absent in summer. In autumn a clear preference for the native vegetation category sites by Guild 3 and 4 species, excluding *S. greyii*, was very evident. The sites recording the highest species richness were river gum open woodland sites in spring, and poplar box and mixed species sites in autumn (Table 6.7w).

For Guild 2 species in Fig. 6.7ix in comparison to other Guilds the most outstanding result was the high level of percentage presence at intensive management category sites including irrigated cropping and water storages in all seasons, and the reduced presence by all species at irrigated cropping category sites in autumn.

Table 6.7.x. Guild 2 species - Presence at percentage of sites
(Species ordered according to ultrasound frequencies – lowest to highest)

	rgf	rgow	pb	gb	mix	cp	git	ic	ws	dc
Spring	C.g. Unid **M.2.** M.3. **S.b.**	M.4 C.g. Unid **M.2.** M.3. S.b.	M.4 C.g. M.2. M.3. **S.b.**	M.4. C.g. **M.2.** **M.3.** **S.b.**	M.4 C.g. Unid M.2. **M.3.** **S.b.**	M.2. M.3. S.b.	M.4 Unid **M.2.** M.3.	M.4 C.g. Unid M.2. M.3. S.b.	M.4 M.2. M.3. S.b.	M.4 C.g. M.2. S.b.
Summer	M.4 **C.g.** **M.2.** M.3. **S.b.**	M.4 **C.g.** **M.2.** M.3. **S.b.**	M.4 **C.g.** Unid M.2. M.3. S.b.	**C.g.** M.2. S.b.	M.4 **C.g.** M.2. M.3. **S.b.**	**C.g.** M.2. M.3. S.b.	**C.g.** **M.2.** S.b.	M.4 **C.g.** **M.2.** M.3. **S.b.**	**C.g.** M.2. M.3. **S.b.**	C.g. M.2. S.b.
Autumn	C.g. Unid **M.2.** M.3. **S.b.**	M.4 C.g. **Unid** M.2. M.3. S.b.	M.4 C.g. **Unid** **M.2.** **M.3.** S.b.	Unid M.2. M.3.	M.4 C.g. Unid **M.2.** **S.b.**	M.4 C.g. Unid M.2. **S.b.**	M.4 Unid **M.2.**	M.4 C.g. Unid M.2. S.b.	M.4 C.g. Unid **M.2.** **M.3.** S.b.	M.4 C.g. Unid M.2. M.3. S.b.

KEY
Species: (M.4) *Mormopterus* sp. 4; (C.g.) *Chalinolobus gouldii*; (unid) unidentified group of calls;
(M.2.) *Mormopterus* sp. 2; (M.3) *Mormopterus* sp. 3; (S.b.) *Scotorepens balstoni*;
Landscape categories:
Native vegetation:(rgf) river gum forest; (rgow) river gum open woodland; (pb) poplar box; (gb) grey box;
(mix) mixed species; (cp) cypress pine;
Intensive management: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping.
(Red) Highest species richness; **(bolded)** High seasonal presence at percentage of sites

Reduced presence at irrigated cropping sites in autumn after cotton crop defoliation and picking and consequent reduction in habitat for insects, is evidence that presence recorded at irrigated cropping sites in spring and summer is directly related to predation on insects in cotton fields. The second result of interest is the seasonal presence relationship between *C. gouldii* and the group of “unidentified calls”. Although all species recorded seasonal variation in percentage presence and distribution, a comparison of the balance between these two groups of calls in summer against spring and autumn suggests that the unidentified calls are most probably seasonally altered *C. gouldii* calls.

For Guild 2 species, the lowest site percentage presence was recorded for the grasslands and isolated tree sites, where an absence or near absence was recorded for *C. gouldii* and *S. balstoni* in spring and summer, the “unidentified calls” in summer, and *Mormopterus* sp. 3 in summer and autumn. *Mormopterus* sp. 2 recorded a similar pattern of presence across all categories, *S. balstoni* recorded consistent presence for summer, a variable presence in spring and a sporadic presence in autumn, *Mormopterus* sp. 3 was most consistent at water storages across the seasons, but varied both in presence and percentage presence across the seasons and *Mormopterus* sp. 4 recorded an inconsistent pattern of low site percentage presence across the seasons. The highest species richness (6) of Guild 2 including “unidendified calls” species (Table 6.7x) was recorded for river gum open woodland, mixed species and irrigated cropping sites in spring only, poplar box sites in summer, and river gum open woodland, poplar box, water storages and dryland cropping sites in autumn.

6.7.9 MICROBAT SPECIES INDEX

A Microbat Species Index compares site percentage presence species richness for the combined landscape categories (Table 6.7y). The landscape categories recording the highest species richness were: river gum open woodlands in spring (14), poplar box and mixed species in autumn (13). Twleve species were recorded each for mixed species and irrigated cropping in spring, poplar box in summer, and river gum open woodland and dryland cropping sites in autumn. The lowest in species richness (5) was recorded for water storage sites in spring, grassland and isolated trees in summer and autumn, and grey box sites in autumn.

Table 6.7.y. **MICROBAT SPECIES INDEX** - Seasonal comparison of Species richness for combined landscape categories (Species ordered according to ultrasound frequencies – highest to lowest)

Season & Guild	**rgf**	**rgow**	**pb**	**gb**	**mix**	**cp**	**git**	**ic**	**ws**	**dc**
Spring Guild 1	**S.f.**	T.a. **S.f.**	**S.f.**		T.a. **S.f.**	T.a.		T.a. S.f.	T.a.	S.f.
Guild 2	C.g. Unid **M.2.** M.3. **S.b.**	M.4 C.g. Unid **M.2**. M.3. S.b.	M.4 C.g. M.2. M.3. **S.b.**	M.4. C.g. **M.2.** **M.3.** **S.b**.	M.4 C.g. Unid M.2. **M.3.** **S.b.**	M.2. M.3. S.b.	M.4 Unid **M.2.** M.3.	M.4 C.g. Unid M.2. M.3. S.b.	M.4 M.2. M.3. S.b.	M.4 C.g. M.2. S.b.
Guild 3	S.g. V.v.	S.g. C.p. V.r. V.v.	**S.g.** **C.p.** V.v;	**S.g.** **V.v.**	**S.g.** V.v. .	**S.g.** V.v.	**S.g**.	**S.g.** **V.v.**		S.g. C.p.
Guild 4	C.m. V.t. N.spp	C.m. V.t.	N.spp		C.m. **N.spp**		N,spp	C.m. N.spp		C.m. N.spp
Spring Total	**11**	**14**	**10**	**7**	**12**	**6**	**6**	**12**	**5**	**9**
Summer Guild 1	**S.f.**	**S.f.**	**S.f.**		**S.f.**	**S.f.**	**S.f.**	S.f.	S.f.	S.f.
Guild 2	M.4 **C.g.** **M.2**. M.3. **S.b.**	M.4 **C.g.** **M.2.** M.3. **S.b.**	M.4 **C.g.** Unid M.2. M.3. S.b.	**C.g.** M.2. S.b.	M.4 **C.g.** M.2. M.3. **S.b.**	**C.g.** M.2. M.3. S.b.	**C.g.** **M.2.** S.b.	M.4 **C.g.** **M.2.** M.3. **S.b.**	**C.g.** M.2. M.3. **S.b.**	C.g. M.2. S.b.
Guild 3	**S.g.** **C.p**.	S.g.	**S.g**. C.p. V.d. **V.v.**	**S.g.** **C.p**	Sg. C.p.	**S.g.** V.v.	S.g.	**S.g.**	**S.g.** C.p.	S.g.
Guild 4	C.m. N.spp	C.m. N.spp	C.m.	**N.spp**	C.m.	**C.m.**		**C.m.** **N.spp**		
Summer Total	**10**	**9**	**12**	**6**	**9**	**8**	**5**	**9**	**7**	**5**
Autumn Guild 1	**T.a.** S.f.	**T.a.** **S.f.**	S.f.		**T.a.** **S.f.**	**T.a.**		**S.f.**	**S.f.**	**S.f.**
Guild 2	C.g. Unid **M.2.** M.3. **S.b.**	M.4 C.g. **Unid** M.2. M.3. S.b.	M.4 C.g. **Unid** **M.2.** **M.3.** S.b.	Unid M.2. M.3.	M.4 C.g. Unid **M.2.** **S.b**.	M.4 C.g. Unid M.2. **S.b.**	M.4 Unid **M.2.**	M.4 C.g. Unid M.2. S.b.	M.4 C.g. Unid **M.2.** **M.3.** S.b.	M.4 C.g. Unid M.2. M.3. S.b.
Guild 3	**V.v.** .	S.g. C.p.	S.g. C.p. V.d. **V.v.**	**V.v.**	S.g. C.p. **V.v.**	C.p. **V.v.**	C.p. V.v.	S.g. V.v.	S.g. V.d.	S.g. C.p. V.v.
Guild 4	C.m. N.spp	C.m. N.spp.	**C.m.** **N.spp.**	**C.m.**	**C.m.** V.t. N.spp.	**C.m.** **N. spp.**				C.m. N.spp.
Autumn Total	**10**	**12**	**13**	**5**	**13**	**10**	**5**	**8**	**9**	**12**

KEY

Species: Guild 1: (Ta) *Tadarida australis*; (Sf) *Saccolaimus flaviventris*;
Guild 2: *(M*4) *Mormopterus* sp. 4; (Cg) *Chalinolobus gouldii*; (unid) unidentified calls; (M2) *Mormopterus* sp. 2;
(M3) *Mormopterus* sp. 3; (Sb) *Scotorepens balstoni*;
Guild 3: (Sg) *Scotorepens greyii*; (Cp) *Chalinolobus picatus*; (V d) *Vespadelus darlingtoni*; (Vr) *Vespadelus regulus*;
(Vv) *Vespadelus vulturnus*;
Guild 4: (C m) *Chalinolobus morio*; (V t) *Vespadelus troughtoni*; (Nsp.) *Nyctophilus* spp.

Landscape categories:
Native vegetation: (rgf) rivergum forest; (rgow) rivergum open woodland; (pb) poplar box; (gb) grey box; (mix) mixed species; (cp) cypress;
Intensive management: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping.

(Red) Highest in spp. richness; **(orange)** Second spp. richness; **(yellow)** Third spp. richness; **(bolded)** High seasonal presence at percentage of sites

6.7.10 CONCLUSION

This chapter has shown conclusively that the highly managed components of the cotton production landscape have been incorporated into the life histories of many microbat species in the study area. The species that have been most able to utilise these elements have been those predominantly grouped together in Guild 2 with foraging patterns that incorporate open spaces. *Scotorepens greyii* grouped into Guild 3 would also appear to have incorporated cotton production elements into foraging patterns. Although probably limited by the roosting habitat in this landscape, the results suggest that these species have been supported or possibly advantaged by, and in fact may now to be dependent upon prey related to cotton production.

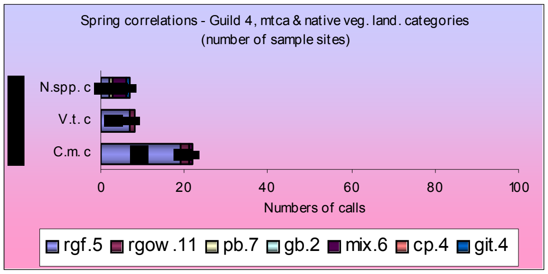
This chapter has also shown that microbat foraging over cotton fields varied between Bt Bolgard II™ cotton varieties and Conventional cotton varieties. The reduction of *Helicoverpa* spp. insect populations bought about by the introduction of Bolgard II™ cotton varieties has suggest there has been an impact upon microbat foraging activity. For this Guild 2 group of species supported by cotton fields, the increasing uptake of Helicoverpa resistant technology, foraging habitat has suddenly been dramatically depeleated, or at least changed from an abundance of high protein moth prey.

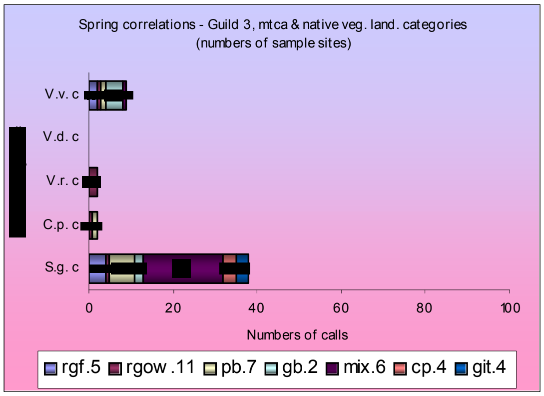
For the species of Guild 1, the results of this study are inconclusive due in part to their high-flying foraging patterns outside recording range. In 2002, with the assistance of powerful light beams, this researcher with Martin Dillon and Graham Richards observed a number of *Tadarida australis* foraging very high above cotton fields across the river from the study area, however their ultrasound echolocation could not be recorded. In studies in California another member of this genus was found to forage on very high migrating populations of cotton pest *Helicoverpa* spp. (Lee and McCracken 2005, McCracken 2002). Observations by the researcher would suggest Guild 1 species may have been disadvantages and advantaged by cotton production, through the reduction of the native vegetative tree canopy that traditionally provided insect foraging habitat, but the increase of moth pest populations. Cotton production has however at least changed the insect prey composition quite considerably.

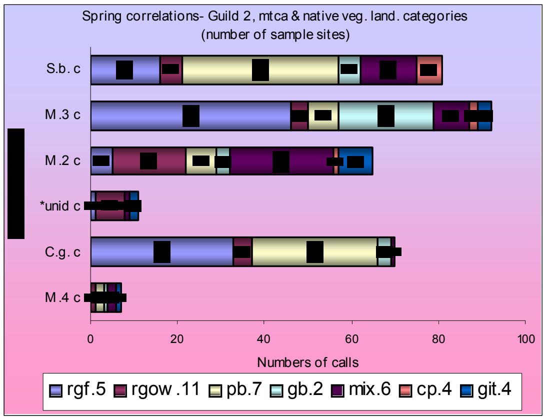
This chapter has however shown that the species grouped together in Guilds 3 and 4 have not only recorded seasonal absence and a much lower presence and call abundance, but they have also not incorporated open spaces and cotton fields into their foraging patterns. Because foraging patterns for these species are slower and foraging strategies are dependent upon closer vegetation communities and a vegetative understorey, these species would appear to be greatly disadvantaged by the cotton production landscape elements and the continuing decline in area and density of native vegetation within the study area.

For Guilds 2 as well as Guilds 3 and 4 species the results in this chapter have urgent management implications.

SPECIES IN THE NATURAL LANDSCAPE - SPRING – microbat total call abundance & total feeding buzz abundance







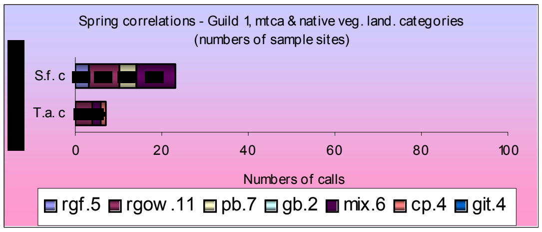
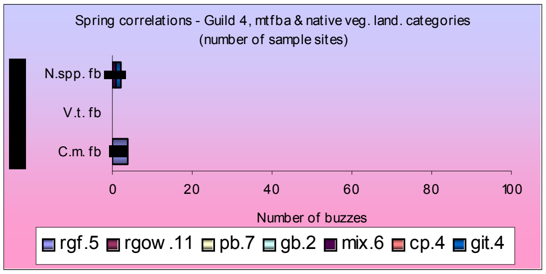
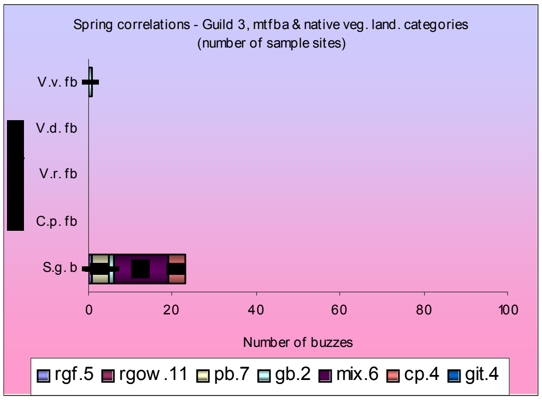
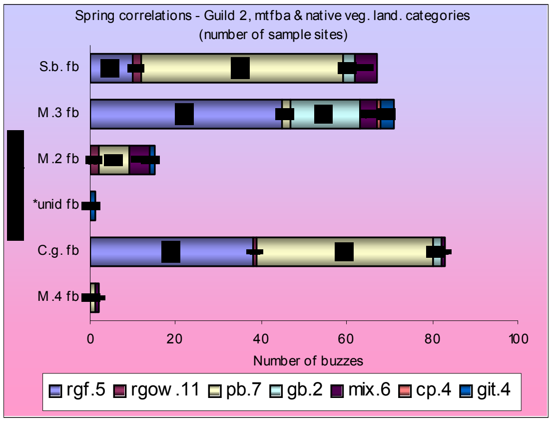


Fig. 6.7.i(a) Spring correlations – **microbat total call abundance (mtca)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category:(rgf)river gum forest;(rgow)river gum open woodland; (pb)poplar box; (gb) grey box; (mix)mixed spp.; (cp)cypress pine; (git)grassls/isol.trees







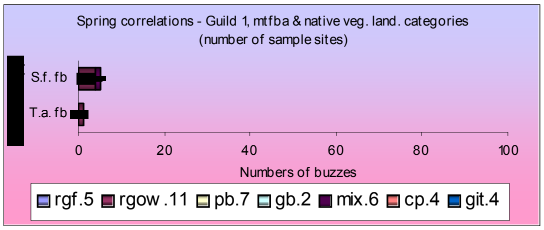


Fig. 6.7.i(b) Spring correlations – **microbat total feeding buzz abundance (mtfba)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (rgf)river gum forest;(rgow)river gum open woodland; (pb)poplar box; (gb) grey box; (mix)mixed spp.; (cp)cypress pine; (git)grassls/isol.trees

SPECIES IN THE NATURAL LANDSCAPE - SUMMER – microbat total call abundance & total feeding buzz abundance

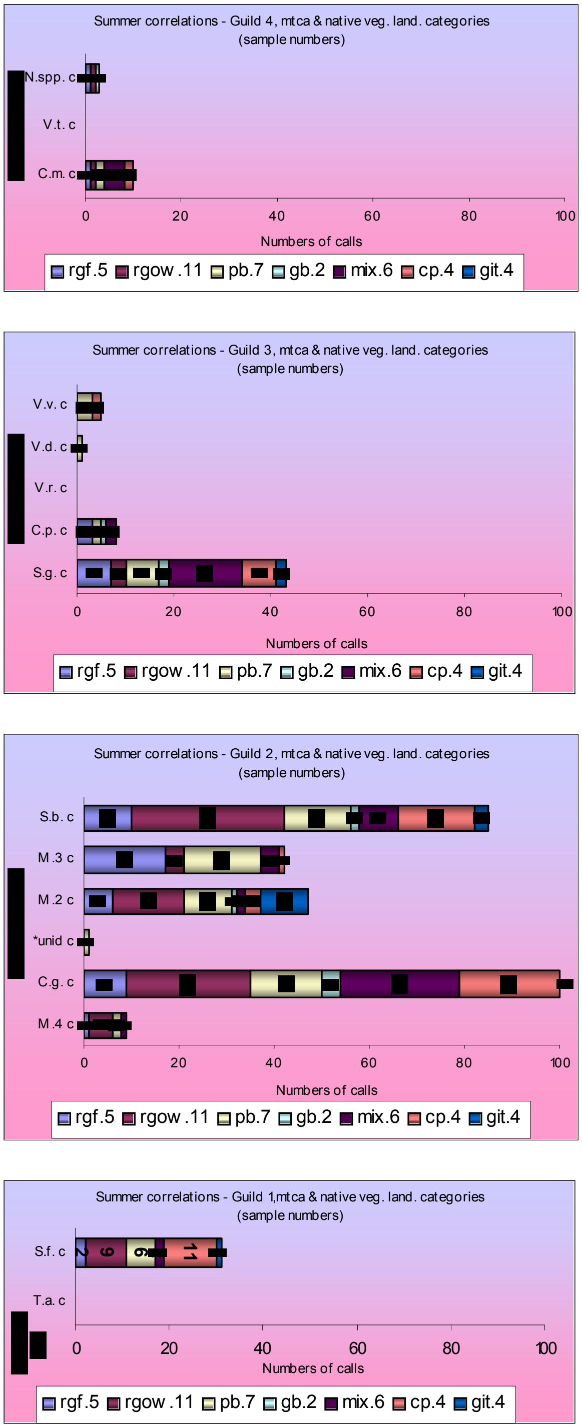


Fig. 6.7.ii(a) Summer correlations – **microbat total call abundance (mtca)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (rgf)river gum forest; (rgow)river gum open woodland; (pb)poplar box; (gb) grey box; (mix)mixed spp.; (cp)cypress pine; (git)grassls/isol.trees

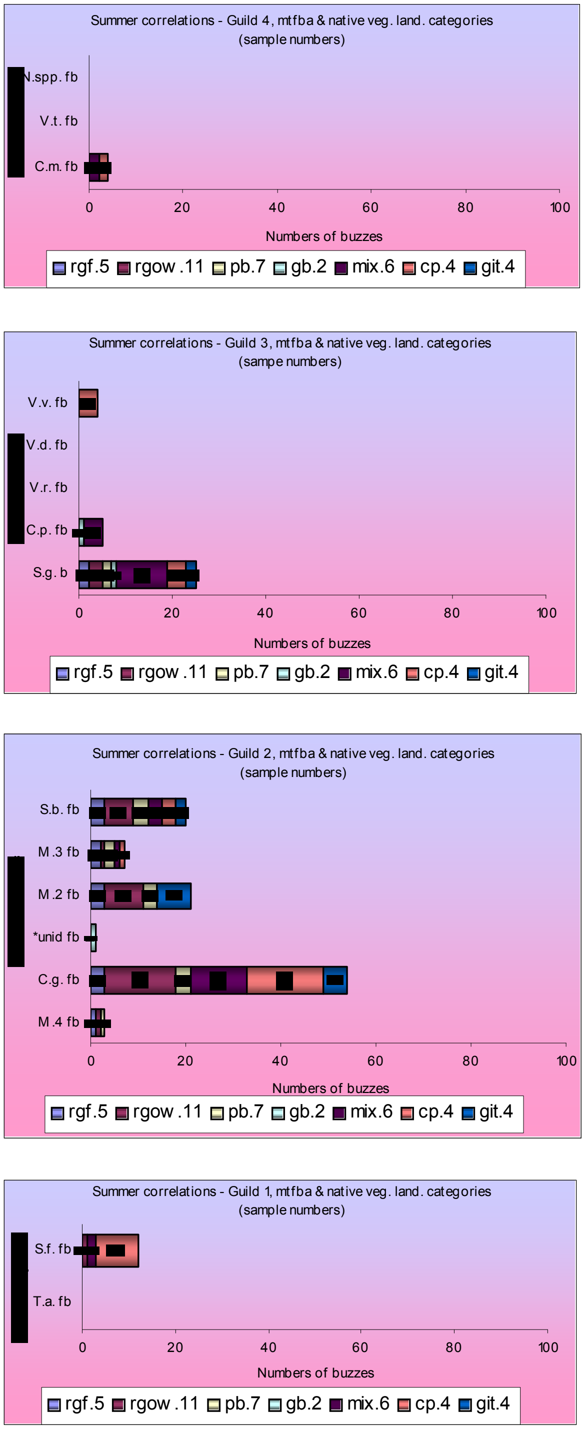


Fig. 6.7.ii(b) Summer correlations – **microbat total feeding buzz abundance (mtfba)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (rgf)river gum forest; (rgow)river gum open woodland; (pb)poplar box; (gb) grey box; (mix)mixed spp.; (cp)cypress pine; (git)grassls/isol.trees

SPECIES IN THE NATURAL LANDSCAPE - **AUTUMN** – microbat total call abundance & total feeding buzz abundance

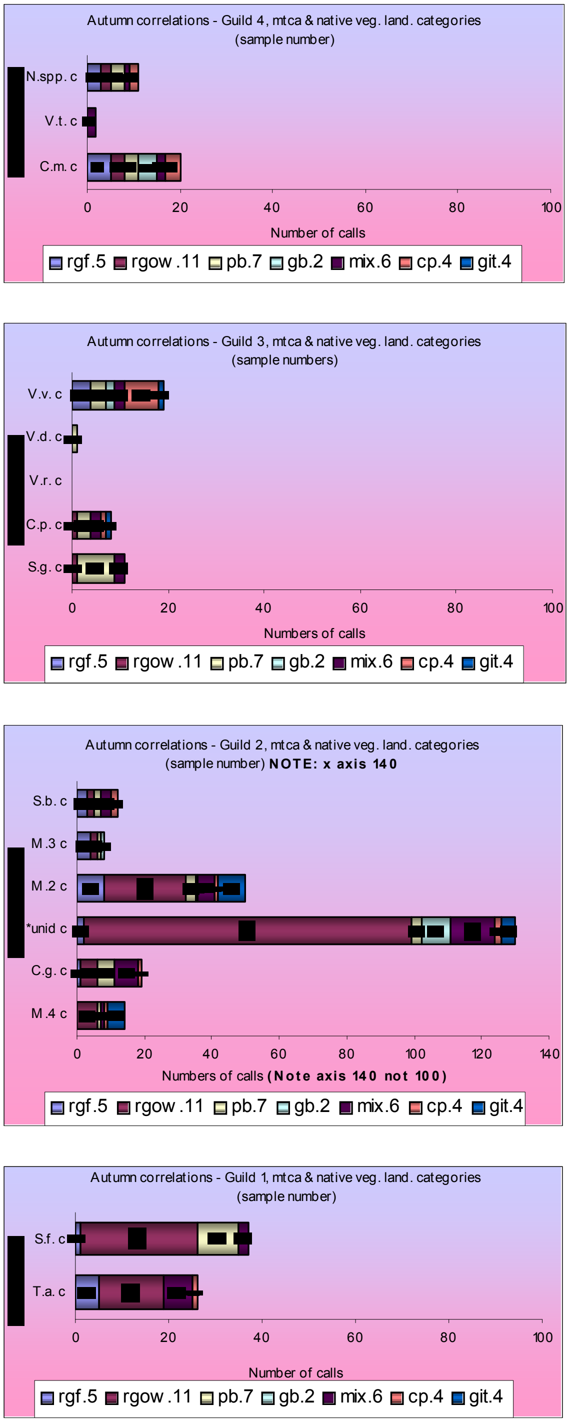


Fig. 6.7.iii(a) Autumn correlations – **microbat total call abundance (mtca)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (rgf)river gum forest; (rgow)river gum open woodland; (pb)poplar box; (gb) grey box; (mix)mixed spp.; (cp)cypress pine; (git)grassls/isol.trees

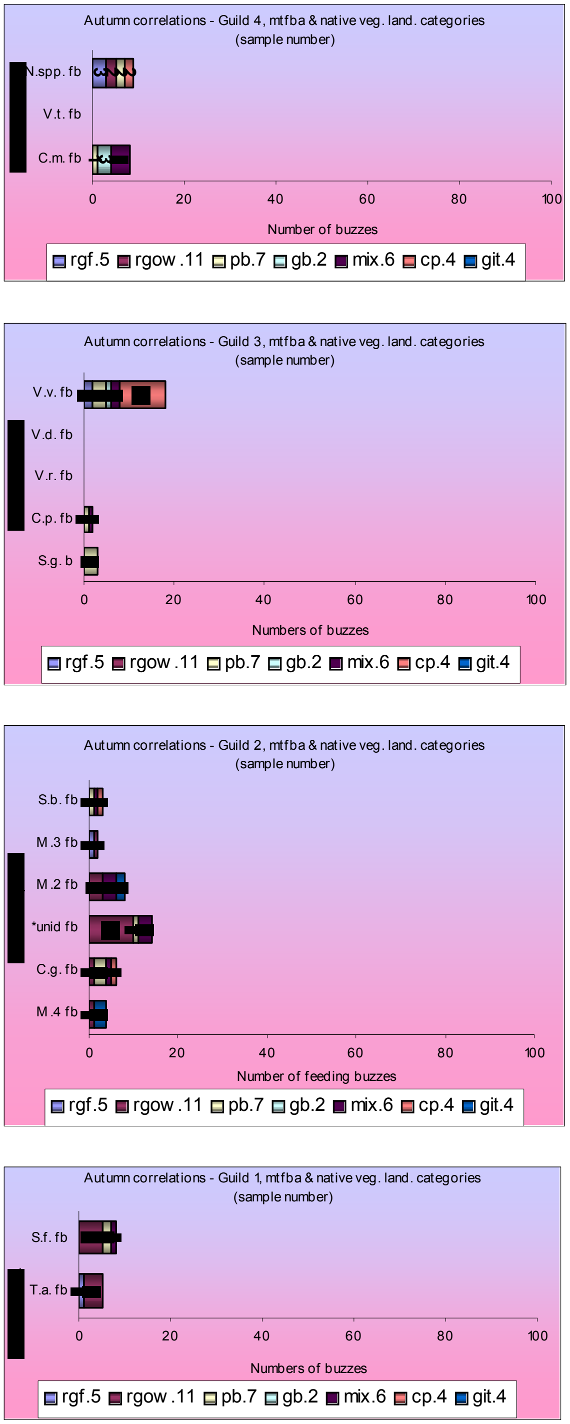
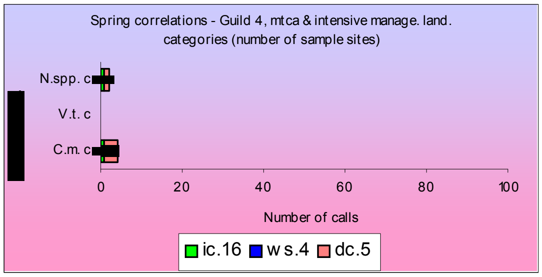
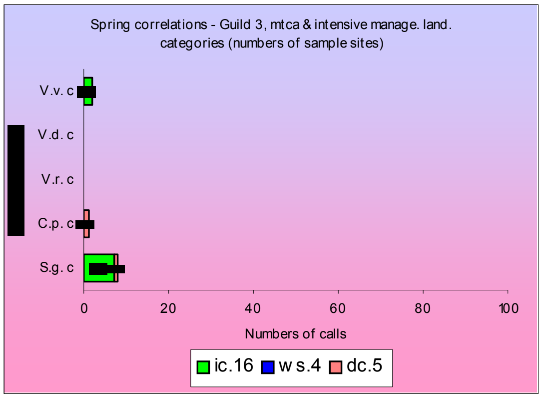
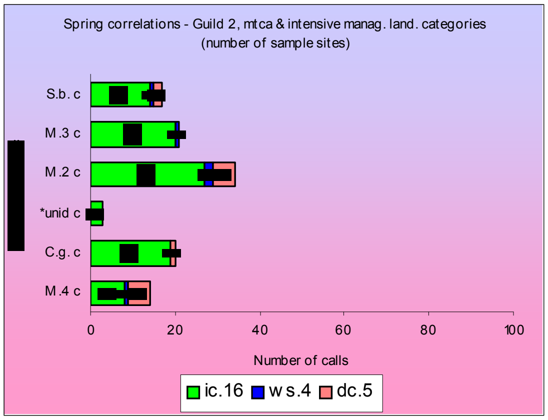


Fig. 6.7.iii(b) Autumn correlations – **microbat total feeding buzz abundance (mtfba)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (rgf)river gum forest; (rgow)river gum open woodland; (pb)poplar box; (gb) grey box; (mix)mixed spp.; (cp)cypress pine; (git)grassls/isol.trees

SPECIES IN THE INTENSIVE FARMING LANDSCAPE - SPRING microbat total call abundance & total feeding buzz abundance







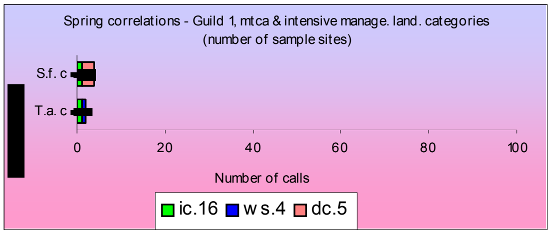
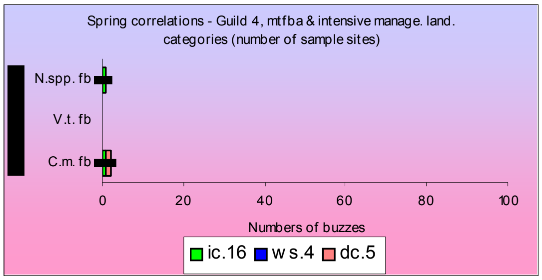
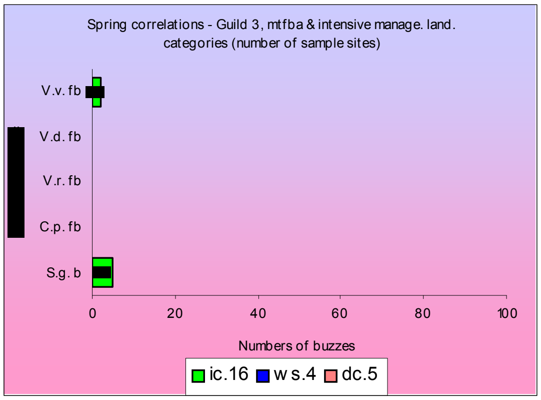


Fig. 6.7.iv(a) Spring correlations – **microbat total call abundance (mtca)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping





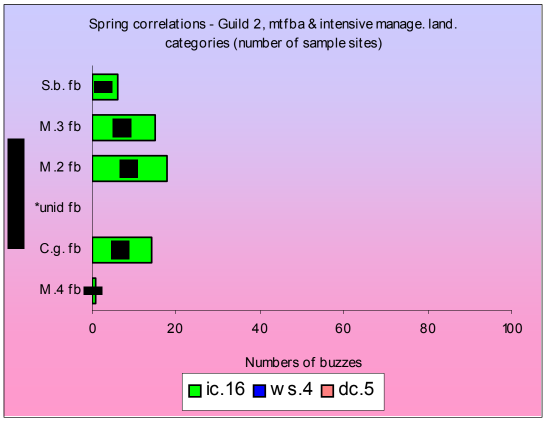


Fig. 6.7.iv(b) Spring correlations – **microbat total feeding buzz abundance (mtfba)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

SPECIES IN THE INTENSIVE FARMING LANDSCAPE - SUMMER microbat total call & total feeding buzz abundance

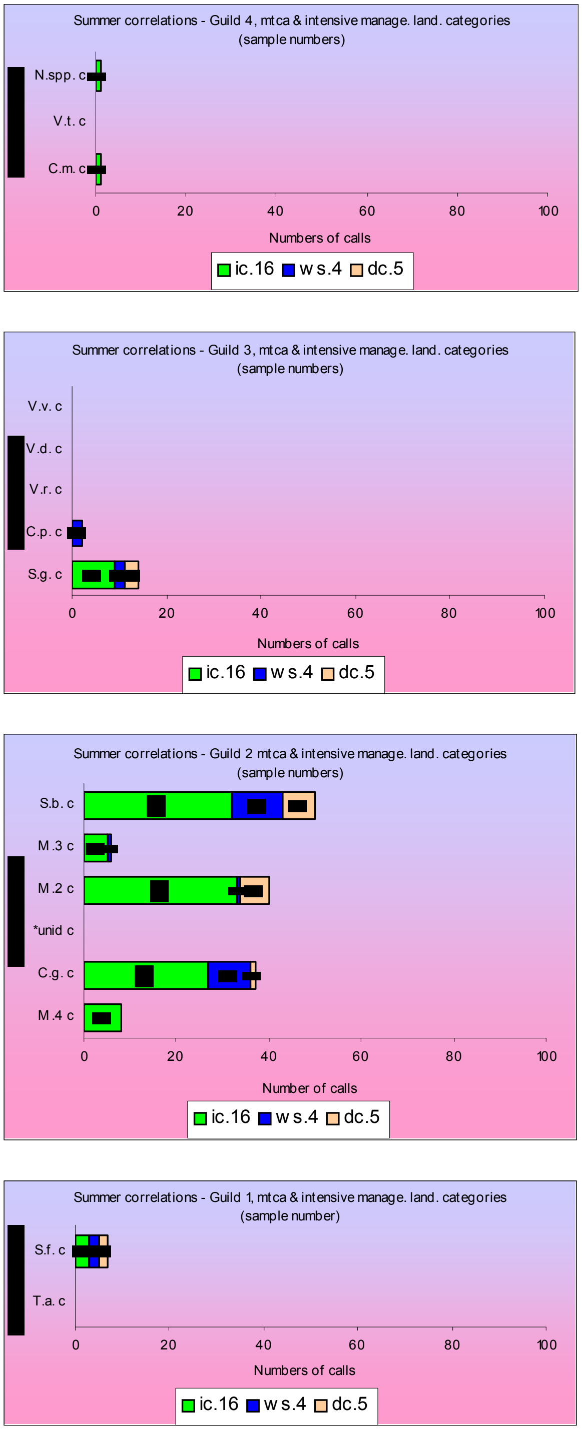


Fig. 6.7.v(a) Summer correlations – **microbat total call abundance (mtca)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
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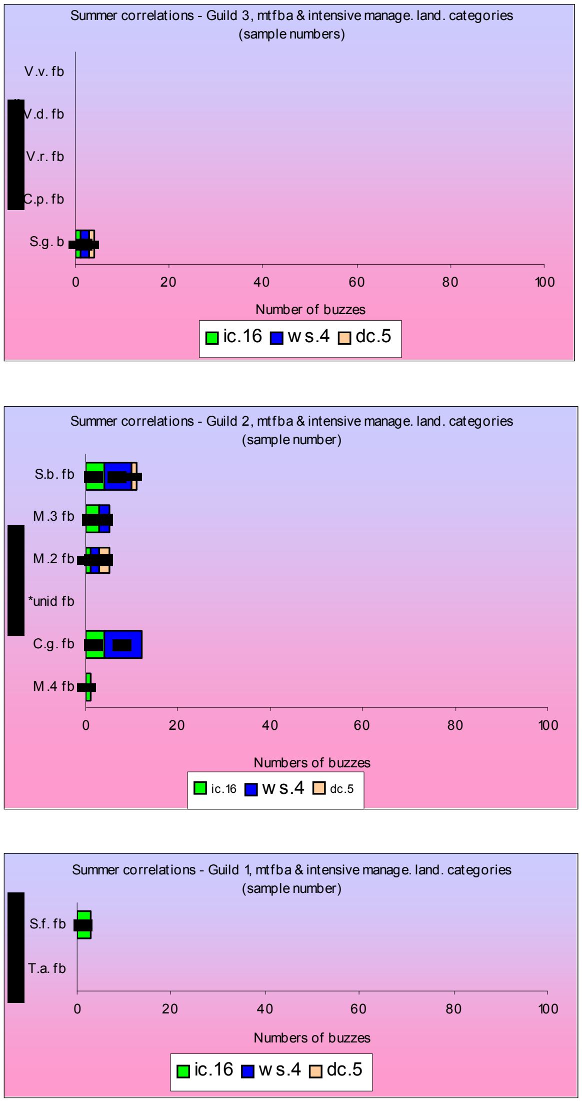


Fig. 6.7.v(b) Summer correlations – **microbat total feeding buzz abundance (mtfba)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

SPECIES IN THE INTENSIVE FARMING LANDSCAPE - AUTUMN microbat total call & total feeding buzz abundance

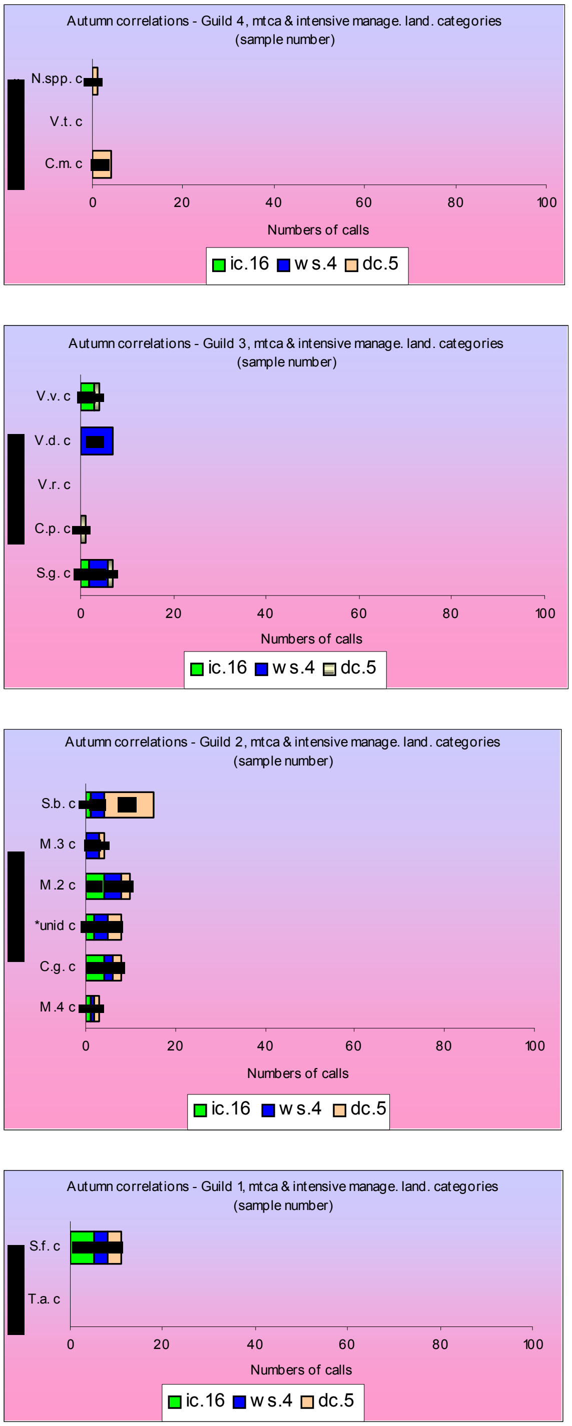


Fig. 6.7.vi(a) Autumn correlations – **microbat total call abundance (mtca)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

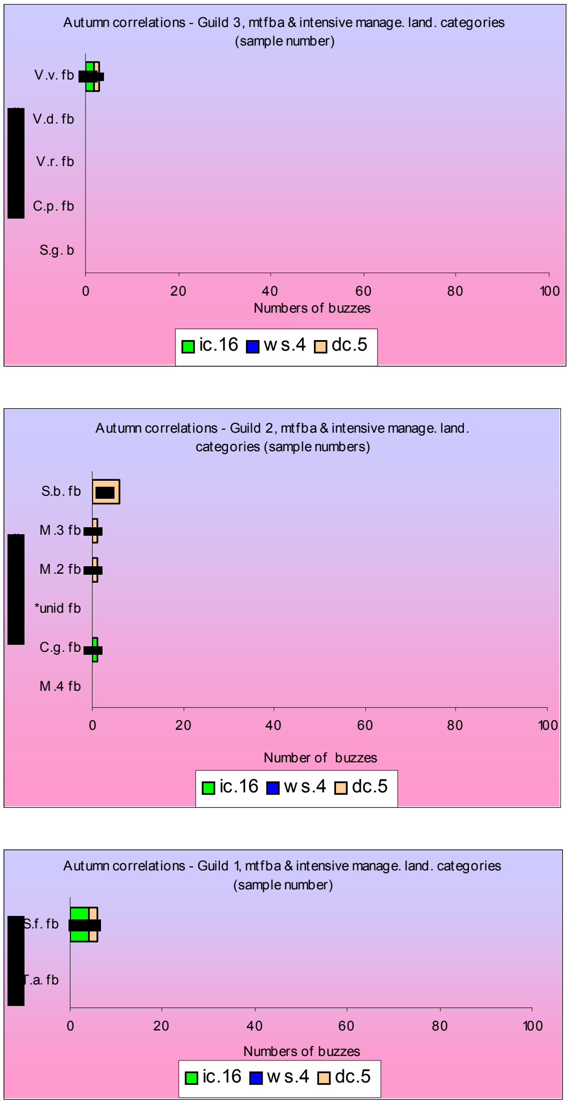
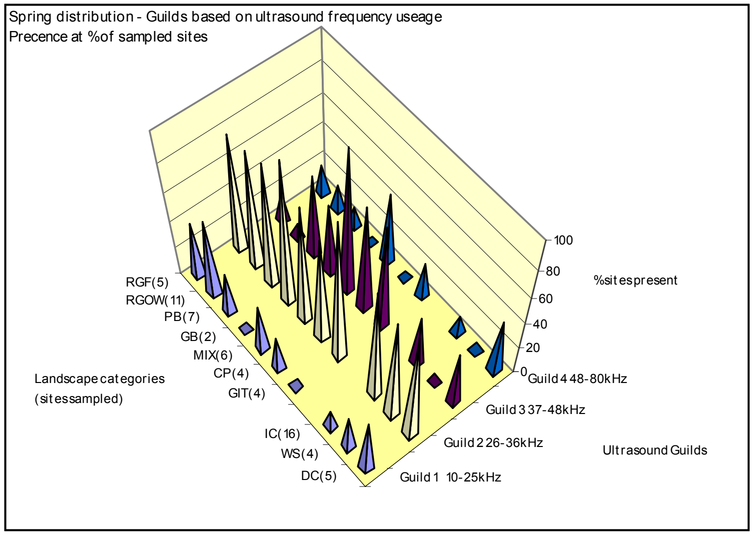
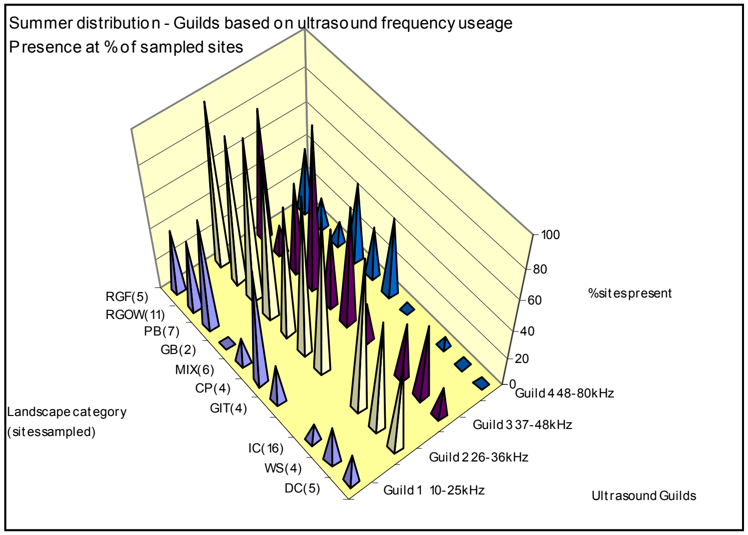
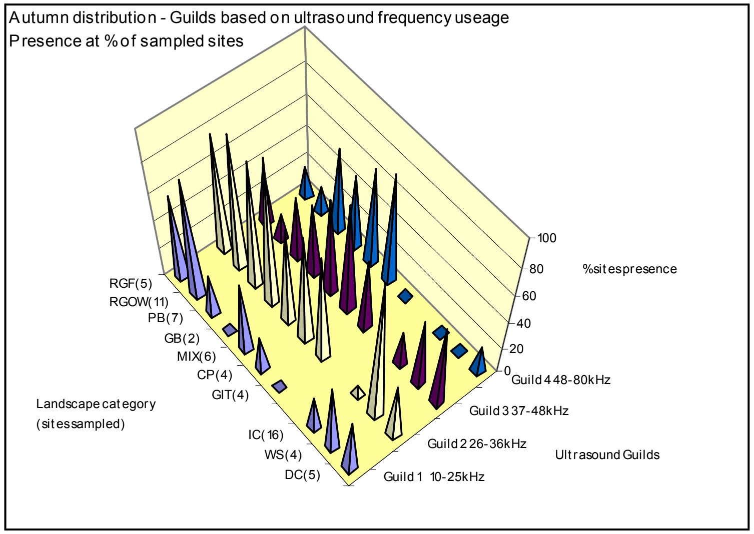


Fig. 6.7.vi(b) Autumn correlations – **microbat total feeding buzz abundance (mtfba)** and Guilds 1-4 (bottom to top; low to high kHz frequencies);
Land category: (ic) irrigated cropping; (ws) water storage; (dc) dryland cropping

SEASONAL COMPARISON OF GUILD LANDSCAPE DISTRIBUTION – PRESENCE AT PERCENTAGE OF SITES







KEY

Landscape categories (in approximation away from the river)

Native vegetation

RGF	river gum forest
RGOW	river gum open woodland
PB	poplar box
GB	grey box
MIX	mixed, PB,GB,belah
CP	cypress pine
GIT	grassland or grassland & isolated trees

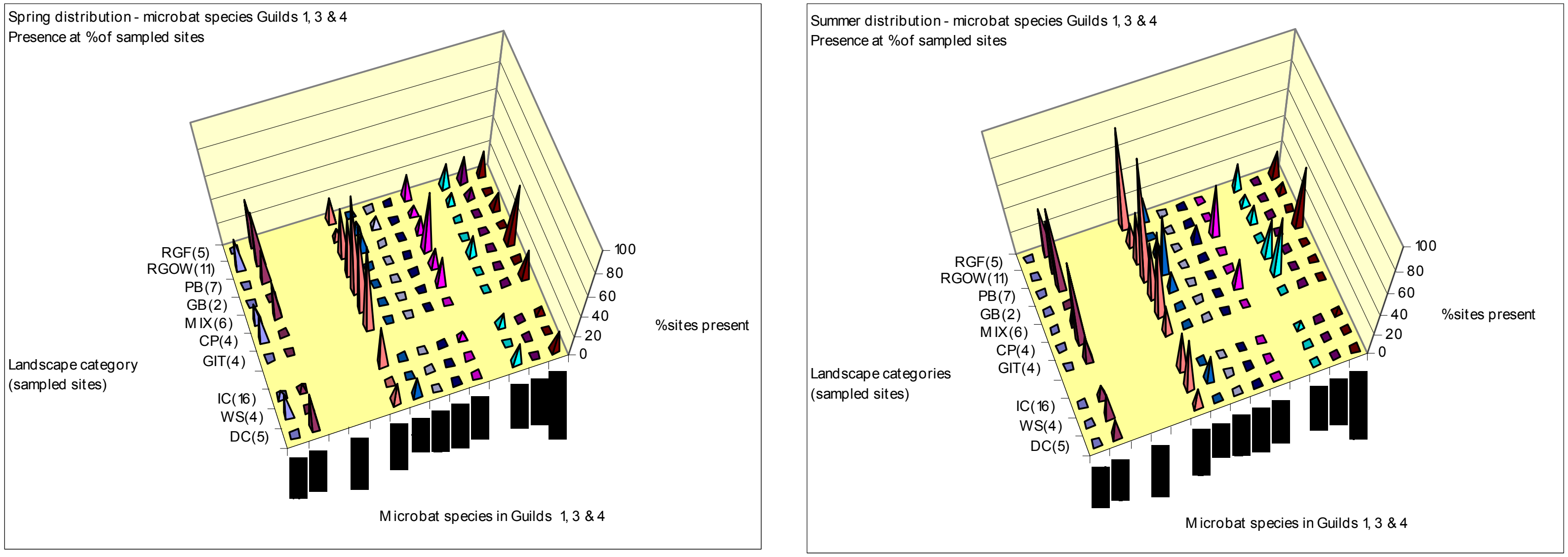
Intensive management

IC	irrigated cropping
WS	water storage
DC	dryland cropping

Guilds of microbat species based on ultrasound frequency ranges

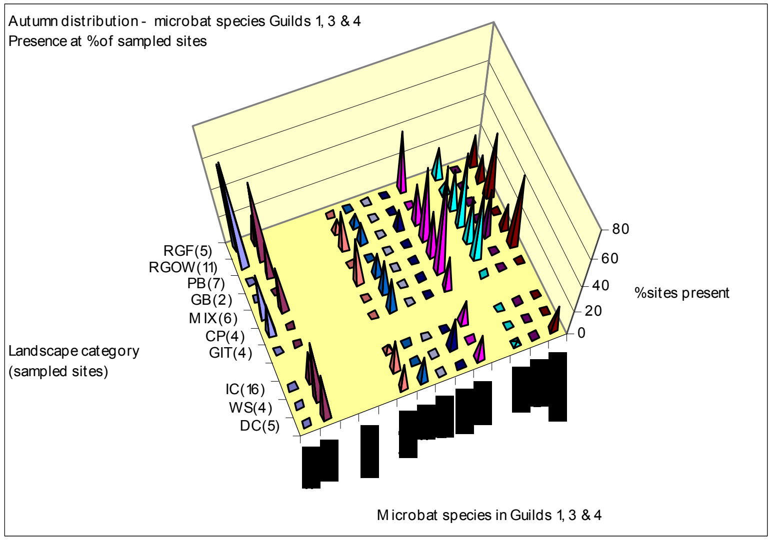
Guild 1	10-25 kHz (2 species)
Guild 2	26-36 kHz (6 species)
Guild 3	37-48 kHz (5 species)
Guild 4	48-80 kHz)3 species)

Fig. 6.7.vii Guilds 1-4 - Comparison of seasonal distribution - presence at percentage of sampled sites (total 64)



Spring distribution - microbat species Guilds 1, 3 & 4
Presence at %of sampled sites

Summer distribution - microbat species Guilds 1, 3 & 4
Presence at %of sampled sites



Autumn distribution - microbat species Guilds 1, 3 & 4
Presence at %of sampled sites

KEY

Landscape categories (in approximation away from the river)

Native vegetation

RGF	river gum forest
RGOW	river gum open woodland
PB	poplar box
GB	grey box
MIX	mixed, PB,GB,belah
CP	cypress pine
GIT	grassland or grassland & isolated trees

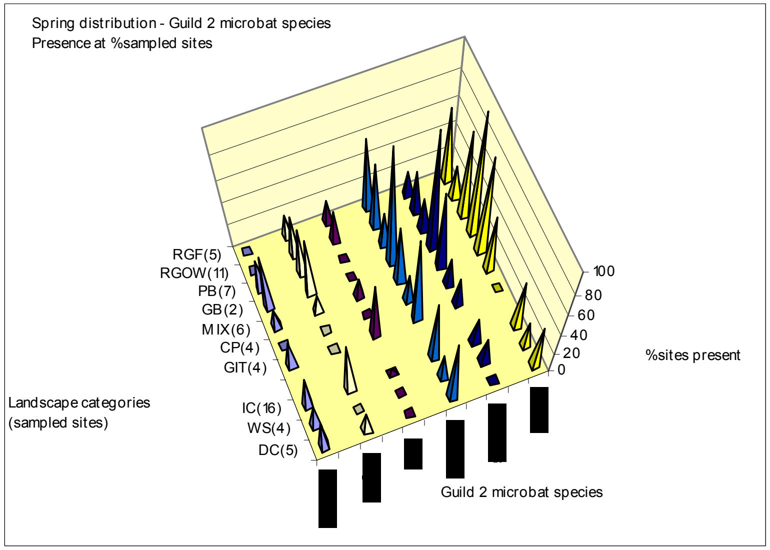
Intensive management

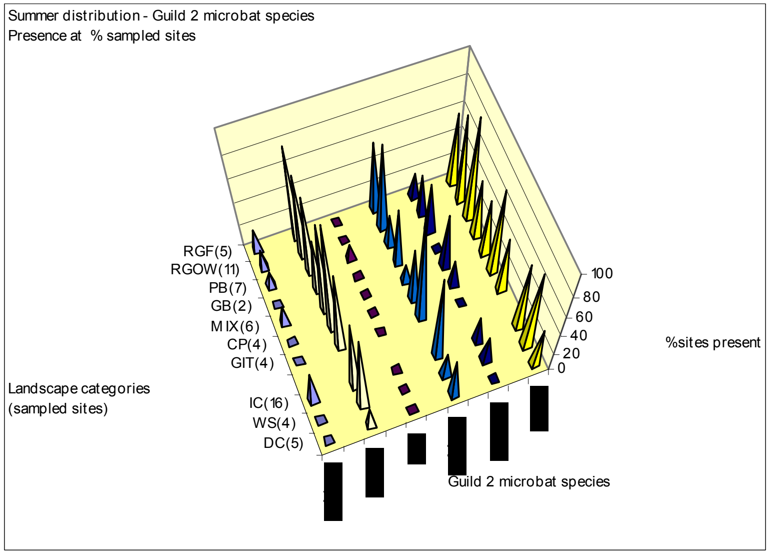
IC	irrigated cropping
WS	water storage
DC	dryland cropping

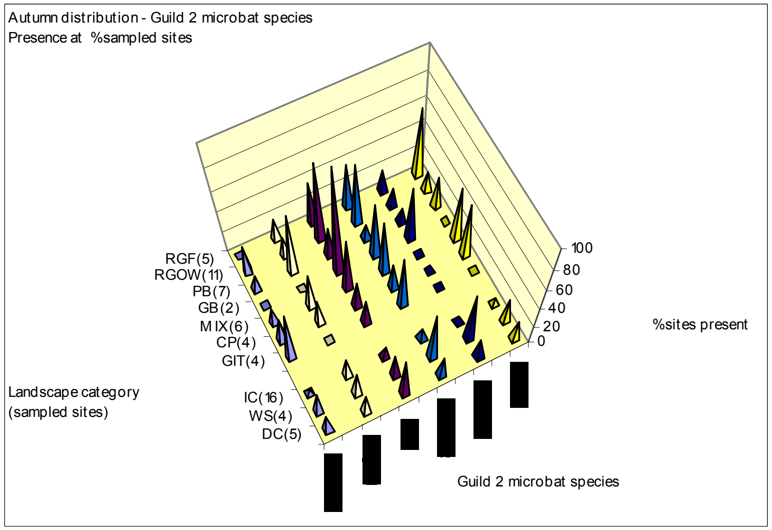
Microbat species (lowest to highest ultrasound frequencies)

Guild 1	T. aust	*Tadarida australis*
	S. flav	*Saccolaimus flaviventris*
Guild 2		species in Fig 6.7.ix
Guild 3	S. grey	*Scotorepens greyii*
	C. pic	*Chalinolobus picatus*
	V. reg	*Vespadelus regulus*
	V. darl	*Vespadelus darlingtoni*
Guild 4	C. mor	*Chalinolobus morio*
	V. trou	*Vespadelus troughtoni*
	Nyct. spp	*Nyctophilus geffroy*, *N. gouldi*, *N. timoriensis*

Fig. 6.7.viii Species within Guilds 1, 3 and 4 - Comparison of seasonal distribution, presence at percentage of sampled sites (total 64)







KEY

Landscape categories (in approximation away from the river)

Native vegetation

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RGOW	river gum open woodland
PB	poplar box
GB	grey box
MIX	mixed, PB,GB,belah
CP	cypress pine
GIT	grassland or grassland & isolated trees

Intensive management

IC	irrigated cropping
WS	water storage
DC	dryland cropping

Guild 2 - microbat species (lowest to highest ultrasound frequencies 26-36 kHz)

M. spp. 4	*Mormopterus*. sp. 4
C. goul	*Chalinolobus gouldii*
Unid	Unidentified calls
M. spp. 2	*Mormopterus* sp. 2
M. spp. 3	***Mormopterus*** sp. 3
S. bals	*Scotorepens balstoni*

Fig. 6.7.ix Species within Guild 2 - Comparison of seasonal distribution - presence at percentage of sampled sites (total 64)

CHAPTER 7 DISCUSSION

At the conclusion of this project during a telephone conversation with one of the participating cotton growers the researcher was taken to task. Within a very research-orientated and highly pro-active industry the grower not only voiced the first question always raised at grower exposure to this research but also raised concerns about research generally. Without exposure to the final research findings the grower reiterated his initial vision for this research in a question "Is the application of this research the manufacture of a microbat call synthesizer for use over cotton crops to scare off *Helicoverpa*?" His next question was "If not, as this research is partly funded by the cotton industry what are the production outcomes?" He expressed frustration with research primarily focused upon improving researchers' careers and not on practical applications. The following discussion attempts to address some of his concerns and the questions posed for this project, and identify implications for the cotton industry.

The first favourable outcome for the cotton industry was that within a very altered, fractured and intensive agricultural production landscape between 14 and 17 microbat species were identified four of which in some regions of Australia are listed as Vulnerable. Implications for the cotton industry are that although at the time of the 2003/04 research, food and roosting resources were available to support such a high diversity of microbats, after 2003/04 what of the future? What impact will widespread adoption of GM cotton and the associated changes have on microbat communities? What impact will lippia management practices, agricultural production creap into native vegetation or increased grazing pressure have on microbat communities?

Species using cotton fields and frequencies audible by hearing insects

The second favourable outcome for the industry was that in spring and summer 17% and 22% of total call abundance, and 20% and 12% of total feeding buzz abundance was recorded over cotton fields. Of the species identified over cotton fields the majority used ultrasound echolocation frequencies audible by hearing insects (including *Helicoverpa* species). By the combination of these results with the evidence gathered from the literature, the implication for the cotton industry is that microbats in the study area were indeed providing an ecosystem service to cotton production with their participation in reducing pest insect populations by (i) direct predation on *Helicoverpa* as well as (ii) interruptions to nightly *Helicoverpa* reproduction.

A corollary to these results was the identification of species that recorded the highest presence over cotton crops and their associated ultrasound frequencies. These species were *Mormopterus* sp. 2. 3 and 4, *Chalinolobus gouldii* and *Scotorepens balstoni* (Guild 2) and *Scotorepens greyii* (Guild 3). The Guild 2 species recorded very high percentages of both total call and total feeding buzz abundance **-** 76% and 78% of spring and summer calls, and 86% and 76% of spring and summer feeding buzzes – with *C. gouldii* recording 16% and 25% of spring and summer calls and 29% and 29% of spring and summer buzzes. In the study area the ultrasound echolocation frequencies utilised by these six species were between 26 – 40kHz.

The implication for the industry of these results is, that if research is to be undertaken into the replication of ultrasound echolocation frequencies the appropriate frequencies and call types have been identified. However such research would need to recognise that the range of social calls and the purpose of many calls utilised by microbats is not understood. Any introduction of reproduced and repetitive call signals may advantageously or disadvantageously influence the activities of (i) individuals of the species utilising the replicated frequencies, (ii) other microbat species, (iii) hearing insect species beneficial to cotton production, and/or (iv) other organisms sensitive to ultrasound. In an altered landscape advantageous for some and disadvantageous for other groups of species, more extensive microbat community research is essential and caution should accompany any introductions of such potentially very disruptive technologies. Would not a more sustainable outcome be the increase in the abundance of all species identified by increasing both the roosting habitat and native vegetation foraging habitat for these species?

A compounding implication for the industry associated with both Guilds 2 and Guild 1 (below) species is, that introductions of **any** tools or strategies to manage pest insects need to consider organisms that are now being supported by cotton production. Sudden removals of food resources (or food resources containg harmful chemicals) have immediate and complicated repercussions. Sudden removal of foraging habitat (or deaths caused by pest management strategies such as attractants) leads to reduced eco system services to cotton production. Conservation biological practices should be considered and implemented wherever possible. Noteworthy examples are the management relationships between the now pest fauna, rabbits and foxes. For foxes the decimation of rabbit populations as a result of calesi virus distribution, removed the major fox prey resource resulting in extreme predatory pressure on an array of indigenous fauna species.

A complex of activity - implications for industry

Another positive result is the identification of seasonal peaks in microbat activity in the study area. Microbat community activity and feeding buzz peaks in spring were two hours after civil twilight and an hour either side of midnight, and in summer up to 60 minutes after civil twilight but continuously throughout the evening decreasing around 12.30am. Although the seasonal surveys did not sample microbat activity between 12.30am and dawn the literature describes another peak in microbat activity prior to dawn. The implication for the cotton industry is that further seasonal and nocturnal research is required, but in the interim to retain beneficial microbats in the cotton landscape, nocturnal aerial insecticide applications should be avoided wherever possible and minimised during the identified times of greatest microbat activity.

Of great interest to the cotton industry is the relationship between insect and microbat calls. There was evidence of possible relationships between microbat calls, feeding buzzes and insect calls. Insect ultrasound call activity may have been associated with insects hearing microbat ultrasound and therefore either stimulated or silenced by a microbat presence. The implication for the industry is that the interrelationships between microbat and insect use of ultrasound in cotton landscapes is not understood and requires extensive research to acquire greater understanding for the management of insect pests. Additionally any research into the use of synthesized microbat calls for the suppression of insect pest populations would need to incorporate these interrelationships.

The separation of nocturnal and seasonal patterns of activity for individual microbat species, and the resultant assemblage complex of highly variable levels of activity, coul have been indicative of both nocturnal and seasonal partitioning of resources particularly in summer. A spatiotemporal distribution study of flight activity and food habitats of three Myotis bat species in the USA found that although flight patterns for each species did not vary when captured alone, at sites where paired species were captured, times and heights of foraging varied (Lee and McCracken (2004). It could be assumed in this very altered study area landscape reduced foraging habitats the time and types of foraging flight patterns for individual species have also been altered. The results of this study do however imply that times of aerial chemical application could regularly coincide with the activity peaks of indivual species and thus could be responsible for changes in microbat species abundance and community species composition. Aerial application of chemicals should therefore wherever possible be conducted during the day and only when absolutely necessary be conducted at night and (i) targeted at insect pest species (ii) varied in nocturnal timing, and (iii) kept to a minimum particularly during summer.

Species using frequencies inaudible by insects

The relevance to the industry of Guild 1 species – the high fast flyers

The two fast flying species in Guild 1, *Tadarida australis*, and *Saccolaimus flaviventris*, utilise ultrasound frequencies generally lower than insect hearing capabilities but forage across open spaces and above the tree canopy. *S. flaviventris* is listed as Vulnerable in parts of Australia, and *T. australis* was absent in summer most probably due to a summer temperature and humidity related contraction of range (Bullen and McKenzie 2005 discussed on page 102 above). Although these species did not show as high a presence or as close a link with cotton fields as the Guild 2 species, there could be several reasons for these results. One explanation could be the height of their flight patterns and thus distance from the recorder. In a study of microbats at five habitat types Menzel *et al.* (2005) found that activity levels above the forest canopy were almost three times greater than within or below the canopy. It was suggested that data collected may not accurately reflect activity of species adapted to forage in more open conditions and thus may not provide an accurate picture of microbat assemblages and foraging habitat useage. Because the low ultrasound frequency ranges used by Guild 1 species are audible by humans, unrecorded calls of *Tadarida australis* were heard during the study thus supporting theimplication of the Menzel *et al.* (2005) research.

The relevance to the Australian cotton industry of these high flight patterns can be demonstrated by the behaviour of another member of the *Tadarida* genus in Californian, USA, cropping areas. *Tadarida brasiliensis* was shown to predate upon very extensive high-flying migrating populations of another *Helicoverpa* species *H. zea*. The daily and seasonal pattern of prey consumption for *T. brasiliensis* was closely correlated to the availability of *H. zea* and fall armyworms (*Spodoptera frugiperda*), both agricultural cropping pests in USA (Lee and McCracken 2005). The Australian *Helicoverpa punctigera* breeds in outback Australia following autumn and early-winter rain and subsequent host plant growth. As plants dry off *H. punctigera* migrate on prevailing south-easterly winds arriving in cotton growing areas in early spring (Gregg *et al.* 1993).

Industry implications are that Guild 1 species activity, particularly *T. australis*, could therefore have been closely linked to early spring cotton production and its associated pests but due to high flight patterns their activities were not recorded. The greater autumn presence recorded for these species may have been related to other non-migratory prey movement. Additionally just as remnant vegetation shrinkage has resulted in reduced availability of above-canopy insect populations, so too could Bolgard II™ induced reductions in *Helicoverpa* movement and population size have resulted in predation upon recently increasing populations of insect pest species with lower flight patterns that in the past have been managed by chemical control of *Helicoverpa* spp.

Slower more maneuverable species - utilising within-remnant habitat

The relevance to the industry of Guild 3 and 4 species

With the exception of one species (*Scotorepens greyii*) two groups of microbats (Guilds 3 and 4) recorded very little or no activity over cotton fields and a stronger presence in native vegetation. All are generally slower species with more manoeurverability and where known their foraging patterns include below the canopy, within vegetation and the understorey and for some, on the ground. Guild 3 species (*S. greyii*, *Chalinolobus picatus*, *Vespadelus darlingtoni*, *V. regulus*, *V. vulturnus*) use ultrasound frequencies audible by hearing insects, and Guild 4 species (*Chalinolobus morio*, *V. troughtoni*, *Nyctophilus gouldii*, *N. timoriensis*, *N. geoffroyi*) use frequencies inaudible by hearing insects. The status of three of these species (*C. picatus*, *V. troughtoni* and *N. timoriensis*) in some regions of Australia is listed as Vulnerable. With the exception of *S. greyii*, in summer this study showed a reduced presence for these species as well as species specific native vegetation locations and presence.

All these species would appear to be vulnerable within the cotton production landscape for two reasons. The first is the decreasing size of remnants and the general lack of a vegetative understorey primarily as a consequence of grazing. The second is the seasonal composition of insect populations. If insect populations across this altered landscape are linked to summer cotton production i.e. movement into and out of summer agricultural crops (Rencken 2003a), insect populations in native vegetation remnants would increase in autumn after crop removal and decrease in spring after summer crops have been established. Subsequently summer insect populations within native vegetation remnants would undergo dramatic depletion and compositional change. For microbat species with foraging patterns limited to "within-vegetation", assured and constant insect prey populations within native vegetation remnants are critical for survival.

Measurement of flight and foraging activity of microbats in Germany (Kusch and Idelberger 2005) found that some species changed some of their foraging patches during summer and other species showed little movement. Temporal difference in patch resource density was proposed as cause for differentiation, and the use of one or different foraging patches over the year may have been dependent upon (i) the seasonal constancy or variability of resources, (ii) the degree of isolation of a patch type, and (iii) the species specific foraging strategy. It would appear that in the cotton production landscape some summer niche landscape resource partitioning associated with patch resource densities and foraging strategies was occurring. In other words microbat use of the landscape was dependant upon both resource availability and competition.

To support both microbat predation of cotton insect pests within remnants of native vegetation surrounding crops as well as the vulnerable Guild 3 and 4 microbat species providing this service, a major implication of these results for the cotton industry is the requirement to not only increase the area but to improve the quality of the native vegetation remnants including the retention of old and dead trees. New plantings of indigenous communities and the establishment and management of indigenous vegetative understoreys are urgently required.

A corollary to this, leading to a greater understanding of the ecosystem services provided by microbats, is an urgency to increase research investigating both pest and beneficial insect presence in, and movement between, native vegetation remnants and crops. A study in Alaska (Baxter *et al.* 2005) showed that emergence of adult insects from stream peaks in early summer in temperate zones, could provide food for riparian consumers such as bats. It was suggested that some predators congregate near streams during peak periods of emergence. Storage dam water releases in Australian cotton production landscapes could act as fluxes if riparian vegetation was present and was complex and in good condition. A comparison of organic and conventional farms in England and Wales, found that insect abundance, species richness, moth species diversity, total microbat activity as well as activity of the dominant microbat species were all significantly higher on organic farms than on conventional farms (Wickranasinghe *et al.* 2003). It was also found that insect abundance was significantly higher in pastoral and water habitats on organic farms than in the same habitat on conventional farms. Such a move towards more organic management practices could increase insect diversity and therefore predatory diversity, abundance and activity resulting in greater economic as well as environmental benefits leading to a more sustainable industry.

In summary

This study has revealed a very complex matrix of relationships – the interrelationships between microbats and their insect food resource, between differing foraging strategies and techniques used by individual microbat species and groups of species to access that food resource, and their consequent nocturnal and seasonal utilisisation of differing landscape components.

The maintenance of such a complex system will require careful management. The techniques used in this research did not allow the identification of microbat or insect species abundance. A number of untrasound calls could mean one bat or insect making a number of passes or many bats or insects making one pass each. Although an array of harp traps was used around a light source over several nights to establish a measure of abundance and to capture species of microbat foraging over cotton crops, the traps were full of insects and spotted with bird faeces, but no microbats were captured. Establishing a measure of abundance in such an open environment will require further more extensive research.

Although most microbat species are opportunistic predators, to maintain even the present species abundance future decisions regarding technologies to manage pest insects should however include consideration of organisms now being supported by cotton production. Such strategies could encompass the provision of alternatives to cotton fields as foraging habitats such as extension of cotton production “trap crop” practices, a shrubby understorey in existing remnants and new plantings of indigenous vegetation communities.

This study has not addressed the roosting resource requirements of the study area assemblage of microbats. The majority of species identified utilise tree hollows as roost sites. Eventhough present remnants contain very old and in some cases senescing trees, because eucalypts develop tree hollows commonly only after 150-180 years (Gibbons and Lindenmayer 2002) and there is little tree recruitment occurring in the research area, a major implication for the cotton industry is the urgent requirement for remnant management strategies to address the approximate 150-year time-gap in tree hollow production. In the interim it is imperative that all old and dead trees be retained to merely maintain the current status of roosting sites and a strategy to encourage the provision of roosting boxes be implemented. Another immediate implication for industry is the urgent requirement for lippia management protocols that exclude the removal of dead trees or fallen timber.

CHAPTER 8 CONCLUSION AND RECOMMENDATIONS

Agricultural landscapes dominate an increasing proportion of world and Australian landscapes. Protected areas, at best 10% of the original landscapes, are able only to protect a small proportion of the world's biodiversity. Although this agricultural landscape study located along the Namoi River in north-western NSW has shown change events over the last 150 years, the most profound landscape changes occurred between the 1960's wool market collapse and the late 1990's expansion of cotton production.

This study however has demonstrated that an agricultural system, one generally regarded as highly debilitating for healthy biological diversity, is supporting a diversity of microbat species almost as high as that within the natural systems in proximity to it. Although it is not known if current agricultural practices can continue to sustain such diversity the results are evidence that a highly specialised mammal fauna has been able to survive in at least diversity within a landscape that has been, and is still continuing to be, witness to profound change.

In addition this study has shown that the microbat fauna has not only been able to tolerate the many landscape changes but have also been able to adapt to them. Microbats have extended their foraging strategies across highly modified cotton fields taking advantage of the many insect species that have also adapted to this crop monoculture. Some of these insect species have thrived and become major cotton production pests exampled by *Helicoverpa* species. A community of between 14 and 17 microbat species has learned to utilise and live within the altered landscape, feeding across the seasons on a variety of insects, including cotton pests. Very little is known as yet about the inter-relationships between bats and insects within cotton fields, but more sophisticated recording devises are exposing greater dimensions in understanding as well as possibilities for application.

Whilst this study could suggest but not clarify the distinct influences of many variables on microbat activity, it could demonstrate that the current landscape is favouring a particular group of species – species that have evolved to forage in open spaces. It has also shown that other species have been less able to take advantage of the cotton cultural landscape. For this reason microbat communities have almost certainly undergone substantial shifts in abundance associated with their use of the cotton landscape and previous clearing of vegetation. This study provides a glimpse of the conditions for the survival of a microbat community in the present landscape - a landscape of continual change.

After many past land-use events to which microbats have adapted, there are two major contemporary events that will impact upon the microbat community of this landscape.

The first profound event has occurred in a crucial landscape element for the microbat community in the research area – the river red gum remnants. This study has shown that the combined river gum forest and open woodland sites in spring, summer and autumn recorded 34%, 27% and 47% of microbat total call abundance and 31%, 20% and 29% of microbat total feeding buzz abundance. Additionally in comparison to other tree species in the study area, river red gums contained the highest number of hollows (MacKinnon unpublished). Since the 1998 floods, lippia (*Phyla nodiflora*) (McCosker 1994) a very invasive exotic groundcover species, has covered the grassy understorey of river red gum forests and open woodlands resulting in reduced soil moisture, extensive soil cracks and holes several meters in depth, and decline in both ground cover diversity and river red gum health. Lippia impacts have been compounded in some areas by lippia management procedures that have incorporated the removal of fallen timber, dead standing trees and some old mature trees, thus removing essential tree hollow roosting habitat for microbats.

The second profound event in this landscape has been the introduction of genetically modified cotton varieties. Although the partly successful one-gene Bt Ingard™ varieties had been utilised previously, in the research area the 2003/04 cotton season saw the limited introduction of the two-gene Bt Bolgard II™ varieties developed to resist the pest moth *Helicoverpa* species. Broad-scale industry-wide adoption of Bolgard II™ occurred in the 2004/05 cotton season immediately after field research for this project.

This research study showed that in 2003/04 spring and summer, cotton fields recorded 17% and 22% of microbat total call abundance and 20% and 12% of total feeding buzz abundance. Although growers in the research area reported little decline in the 2003/04 egg-lay data for *Helicoverpa* spp. this study revealed obvious reductions in microbat call and feeding buzz activity over fields of Bolgard II™ cotton varieties compared to Conventional cotton varieties. The introduction of Bolgard II™ varieties resistant to *Helicoverpa* spp. would be expected to depress populations of *Helicoverpa* spp., and the results showed microbat activity, an indicator of insect prey abundance, was much lower over Bolgard II™ crops.

The ramifications of these results are two fold **-** (i) it could be extrapolated that microbat foraging over cotton fields had primarily been related to *Helicoverpa* species, and (ii) consequent microbat adaptation to and their resultant support by cotton fields has meant that since the 2003/04 cotton season there have been very sudden reductions in microbat prey resources as well as foraging habitat at least in the study area.

It is ironic that the majority of the microbat species incorporating cotton fields into their foraging habitat also utilise the ultrasound frequencies within hearing insect capabilities, including *Helicoverpa* species. Therefore any sustained decrease in *Helicoverpa* populations resulting in reductions of microbat ultrasound activity, in turn will reduce the predatory ultrasound pressure on remaining *Helicoverpa* populations as well as any other hearing insect pests within cotton fields.

Thus the accumulative consequences in the research area of (i) the invasion of lippia and (ii) the introduction of Bolgard II™ cotton varieties, are that the status of both roosting and foraging habitat has changed suddenly for even the most adaptive of the microbat species. One such identified adaptive species, *Chalinolobus gouldii*, in other research has been shown to select roost sites in dead limbs of old living river red gums (Lumsden *et al.* 2002a). This study has provided baseline data for *C. gouldii* presence in the study area. Further research should establish and track changes in abundance.

EXTENSION OF THESE FINDINGS

In conclusion the grower's statement and question "Yes we know that we have to look after our remnants, and I am doing that, but what is the production benefit?" (conversation Chapter 7) reveal gaps in knowledge and understanding. Underlying this statement is an assumption that any ecosystem services provided to cotton production by remnants of indigenous vegetation (including any beneficial insect and microbat predatory organisms supported by shelter or roosting sites in native vegetation) are not production benefits. The project has shown that remnants of native vegetation in the study area are **not** being “looked after”. It is essential that such gaps in understanding and knowledge be addressed.

The researcher has recently been appointed as Biodiversity Extension Catchment Officer for the Border Rivers-Gwydir Catchment Management Authority (CMA) based in Moree, another cotton production area 100k north of the study area. The major focus of this position is the establishment of products and activities to raise awareness of biodiversity. The CMA appointment was instigated by the interest this microbat research has generated within the cotton industry and the community, and the recognition that it could provide an excellent extension tool for land management change. The appointment is a very favourable action research outcome for this Masters of Philosophy project providing an avenue for the practical application of research results and a method of addressing the landowner absence in knowledge and understanding.

As can be seen from the “Nycto geoff” story (frontice) this microbat research promised possibilities for attitudinal change by the knowledge of microbats. Embedded into the Biodiversity Extension project described above is a process and structure for assessing attitudinal and behavioural change bought about by knowledge of the microbat research results described in this thesis. Attachment 8A identifies the extension activities undertaken during the course of this research.

RECOMMENDATIONS

The overall recommendation from this research is the production of a report to assist the preparation of extension material and agricultural industry management guidelines for microbats. Specific recommendations from this research fall into three differing categories - for industry, for research, for conservation - and are set out below.

Recommended actions for industry include:

1. WITHIN INTEGRATED PEST MANAGEMENT (IPM):

- the incorporation of microbats as beneficial organisms.

2. WITHIN IPM AND BEST MANAGEMENT PRACTICE (BMP):

- change useage of non knock-down insecticides to knock-down insecticides (to avoid microbat ingestion of insects containing chemicals eg. associated with attractants);
- adoption of recommended times for aerial chemical application (to avoid nocturnal application where ever possible; and when not possible to avoid times of greatest microbat activity particularly after sunset, thus avoiding impacts on individual microbat species);
- adoption of practices recognising requirements of microbats and other fauna adapted to and supported by cotton production such as insect populations.

3. WITHIN BMP, ADOPT IMPLEMENTATION STRATEGIES TO:

- retain all existing remnants of native vegetation by:
  - prohibiting "production creep" into remnant vegetation;
  - retaining existing remnants as age class structures including dead trees;
  - excluding removal of dead standing trees & fallen timber in lippia management.
- improve the quality of existing native remnant vegetation by:
  - adopting BMP for lippia ;
  - fencing off all riparian vegetation to restrict grazing;
  - limiting grazing to facilitate tree, shrub and groundcover recruitment and growth;
  - planting indigenous trees species where recruitment does not occur (including *Eucalyptus camaldulensis* for early tree hollow development);
  - planting patches of indigenous shrub/tree understorey species to increase understory complexity;
- establish new areas of indigenous vegetation communities to provide:
  - increased patch size and connectivity;
  - links for flora and fauna movement in preparation for global warming impacts;
  - tree hollows - immediate (recommended microbat roosting boxes), and into the future (*Eucaluptus camaldulensis* or other appropriate fast growing indigenous tree hollow producing eucalypt species managed for early tree hollow development).

Improved remnant health, increased indigenous plantings together with tree hollow development and management will provide increased ecosystem services to production through the provision of habitat for microbats. Where ever possible local cohorts of vegetation species should be used with reference to species in Table 8a and Chapter 5.

Table 8a. List of indigenous species for the study area (Chapter 5)

Absent or near-absent species (many form the tall shrub, small tree vegetation understorey layer)			
brigalow	*Acacia harpophylla*	rosewood or boonery	*Alectryon oleifolius*
wild willow	*Acacia salicina*	ti-tree	*Leptospermum flaviventris* or *Melaleuca* spp.
river coobah, belalie or euming	*Acacia stenophylla*	dibble, possibly bumble or wild orange	*Capparis mitchelli*
myall	*Acacia pendula*	wilga	*Geijere parviflora*
		quinine or bitter bark	*Alstonia consticta*
Near-absent species * (includes tree species sparsely represented in today's landscape)			
ironwood	*Acacia excelsa*	ironbark	*Eucalyptus creba* or *Eucalyptus melanophloia*
carbeen	*Corymbia tessellaris*	apple	*Angophora floribunda*
coolibah	*Eucalyptus coolabah*	whitewood	*Atalaya hemiglauca*
Other species present in the current landscape			
bimble	*Eucaluptus populnea*	oaks (river oak)	*Cassuarina cunninghamiana*
gums (river red gum)	*Eucalyptus camaldulensis*	oaks (possibly bull oak)	*Cassuarina luehmanni*
belah	*Casuarina cristata*	pine	*Callitris glaucophylla*

***** some not mentioned in Chapter 5   Many of these species are associated with differing soil types.

Recommended research for industry (within cotton production landscapes) investigation of:

1. microbat communities, activities and distribution – long term seasonal studies to gain understanding of change;
2. insect population (pest and beneficial) presence in native vegetation, and seasonal movement between native vegetation and cropping landscape elements;
3. interrelationships, in the use of, and response to, ultrasound, between
    - hearing insect species, and
    - microbat species;

    to gain greater understanding for future IPM strategies.
4. if synthesized microbat ultrasound introduction is contemplated - interrelationships and impacts for microbat and insect species of ultrasound frequencies utilised by Guild 2 species - aimed at understanding the impacts and implications;
5. roost site selection of
    - Guild 2 species,
    - all idendified species within the cotton production landscape -

    aimed at –
    providing greater knowledge and therefore greater adoption of microbats in IPM, and
    preservation and provision of suitable microbat roost site habitat for species foraging over cotton fields;
6. roost box trials - type, placement and utilisation - in new plantings and old remnants for all microbat species identified in this study.

Recommended actions for conservation within intensive agricultural landscapes – investigation of:

1. Best Management Practice for lippia;
2. methods of establishing indigenous vegetation and early tree-hollow development;
3. preparation for global warming – for microbats , other fauna and agriculture.

Activities undertaken during the course of this research project

Date	**Activity (p) - presentation; (t) – talk**
October 03	Publication of early tree hollow results in "Improving biodiversity on cotton farms", "Managing Riparian Lands in the Cotton Industry", CRDC & L&W Australia.
November 03	Conducted third meeting with participating growers post to autumn landscape survey, accompanied by Questionnaires recording awareness and expectations. (t)
10.12.03	"**Insectivorous bats, irrigated cotton, native vegetation remnants and intensive production landscapes**", at "Bugs, birds and bats: conservation biological control" symposium, Ecology Society of Australia Conference, Armidale. (p)
9 & 11.3.04	"**A contributor to IPM and crop health that we haven't known about – bats**!" *Cotton field days and Crop judging tours, Upper Namoi Cotton Growers Association*, Boggabri and Gunnedah. (t) (t)
29.5.04	"Microbats in a cotton production landscape – are there any? if there are, where are they, and what are they doing?**"** ***A Call on Cotton, Tour & Workshop for Post Graduates*****,** **Cotton Research and Development Corporation, Narrabri. (p)**
16.6.04	"**Can microbats provide a kick start for viewing vegetation remnants and biodiversity as cotton production values?**" Australian Cotton CRC 5th Year and Annual Review, Narrabri. (p)
21.6.04	"**Bats in cotton landscapes**" "Biodiversity – Remnant Vegetation and Soil Health" workshop, Warren. s.u.c.e.s.s. Stakeholders uniting communities and catchments exchanging sustainable strategies, Central West Catchment Management Authority, DIPNR and Greening Australia.(t)
7-8.7.04	**"Can microbats provide a kick start for viewing vegetation remnants and biodiversity as cotton production values?**" Land & Water Australia Post Graduate workshop, Canberra. (p)
12.8.04	**"What value are wetlands and bats to your farm . . and vice versa?"** Hands-on-research workshop, 12th Australian Cotton Conference, Australian Cotton Growers Research Association Inc., Broadbeach, Queensland. (interactive workshop x 3)
16&17.8.04	N.S.W. Young People's River Health Conference, Narrabri - Cotton CRC, AFFA, Namoi & Gwydir Border River CMAs, NSW Agriculture, CRDC, MDBC. (interactive display)
26.10.04	Field discussion – **Vegetation and bats**; & dinner discussion MDBC Community Advisory Committee visit to ACRI – dinner discussion, Narrabri (t)
23.11.2005	"**Words and Ultrasounds – reconstructing conservation concepts for cotton landscapes**", Rural Futures 2020, Research Forum, University of Sydney. (p)
7.2006	Vegetation Field Day, Moree, Border Rivers-Gwydir CMA (p)
7.2006	"**Bats, sounds and hollows**" Croc Fest, Moree, Border Rivers-Gwydir CMA (2 days of short workshops to groups of Junior School)

Grower Magazines and Articles:	
8.4.04	Lyon, N. 2004. "Cottoning on" to bats, Vegetation success . . and no cut in profits on "Mollee", *The Land*.
	Lovett, S., Price, P. and Lovett, J. (2003). *Managing Riparian Lands in the Cotton Industry*, Cotton Research & Development Corporation, Goanna Print, Canberra.
Media interviews:	
December	Cobb, Simone, 2003. Bats and cotton from the ESA Conference, *Rural Report*, ABC Radio New England Northwest.
31.1.04	Deblass Alexandra, 2004. Bugs, birds and bats cleaning up in cotton crops, *Earthbeat*, Radio National. 31st January.

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