The ecology and conservation of the Flock Bronzewing Pigeon *Phaps histrionica*

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Peter L. Dostine Date: 24/8/09

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Abstract

The Flock Bronzewing Pigeon is a charismatic, iconic species of the open grassy downs of inland Australia. It is a ground-nesting, ground-feeding granivorous bird and is potentially sensitive to changes in the characteristics of ground layer vegetation induced by grazing or changed fire regime. In concert with many other vertebrate species it declined precipitously in the southern part of its range probably due to changes in vegetation composition and productivity caused by excessive grazing by sheep and subsequent transformation of suitable habitat by agriculture. It demonstrates a pattern of northward range contraction shared by several other bird species. The process of decline may be ongoing, but is masked by dramatic year to year variation in abundance and distribution in response to fluctuations in the distribution of resources.

The species has strong affinities with Mitchell grasslands and chenopod shrublands; its current stronghold is the Barkly Tableland of the Northern Tableland and the Channel Country of far south-west Queensland. Mitchell grasslands and *Chenopodium* swamps are highly valued as a grazing resource, and both are under-represented in the reserve system. Consequently, adequate and effective conservation measures for this species will require deliberate planning for sympathetic management of pastoral lands based on comprehensive information of year-round habitat requirements and knowledge of the spatial strategies of the species.

A review of historical records indicates that the species vacated the temperate portion of its range within decades of the occupation of grassland plains by sheep. Sparse contemporary records suggest that a suite of ground-dwelling vertebrates declined simultaneously.

Locality records were collated to (i) describe spatial patterns and model broad-scale habitat correlates, and to (ii) examine temporal changes in distribution in relation to rainfall patterns. Modelling of environmental variables associated with presence and pseudo-absence data identified a set of predictor variables including soil type, mean rainfall, elevation and longitude. Temporal analyses suggested broad-scale reconfiguration of populations in response to rainfall driven patterns of plant productivity.

Community-based surveys were conducted to augment locality records and to derive additional data on patterns of occurrence. Distributional patterns correspond with modelling results. Respondents to mail-out surveys identified years of high abundance of Flock Bronzewing Pigeons which correspond with periods of above average rainfall and positive

values of the Southern Oscillation Index. Results of a survey of landholders over eighteen months identified an association between Flock Bronzewing Pigeon abundance and patterns of plant productivity indexed by broad-scale satellite–derived data. These results suggest that the species is serially nomadic throughout a large area of suitable habitat beyond core areas.

Broad-scale studies of the patterns of occurrence were complemented by intensive field studies mainly on the Barkly Tableland. Flock Bronzewing Pigeons feed on seed of a limited set of plants, mostly annual or ephemeral herbs, growing in the inter-tussock spaces in the grassland. Modelling of habitat attributes based on detection of signs and observations of bird use found that the species favoured sites with high abundance of the large-seeded annual grass *Chionachne hubbardiana*, and the ephemeral herb *Wedelia asperrima*, usually within grasslands in which Hoop Mitchell grass was at least co-dominant. Grassland composition and abundance of seed of favoured food plants varied between years consistent with variation in rainfall. Data on movements of an individual Flock Bronzewing Pigeon tagged with a satellite tracking device showed that it remained within a large 'home-range' for several months prior to undertaking movements resulting in a net displacement of >200 km after substantial rainfall in the early wet season to a distinct and different vegetation type. This behaviour is supported by data on dietary habits and field observations.

Data on plant community composition from two large-scale grazing trials in relevant black-soil habitats were analysed to determine the effects of grazing pressure on the abundance of known significant food plants. Results were confounded by prior grazing history and experimental design but suggested that two species of food plant, *W. asperrima* and *Trichodesma zeylanicum*, persist in grazed landscapes and may increase in response to grazing pressure, whilst a third species, *C. hubbardiana*, may be sensitive to grazing pressure.

The conservation management of Flock Bronzewing Pigeons will require ongoing good grazing management practices to maintain perennial grasslands and the full complement of interstitial species, and other used habitat components such as chenopod swamplands. Practices such as rotational wet season spelling will allow seeding of species and food for granivorous organisms. The re-introduction of fire into Mitchell grasslands may increase heterogeneity in plant species composition within grasslands. Conservation planning will require systematic planning and involvement of pastoral interests to maximise habitat options for this species.

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Chapter 1: INTRODUCTION

1.1 INTRODUCTION

Dr William MacGillivray practised medicine in the mining township of Broken Hill in western New South Wales in the first decades of the 1900s. From Broken Hill MacGillivray pursued his interests in natural history: he was a keen amateur ornithologist, an avid collector of bird eggs (MacGillivray 1910) and Aboriginal stone tools, and an active member and office-bearer of the newly formed Royal Australasian Ornithologists Union (D'Ombrain 1933). He published several articles on the bird life of the region, including descriptions of encounters with the mercurial Flock Bronzewing Pigeon *Phaps histrionica* (MacGillivray 1901, 1929, 1932). MacGillivray was born on Kallara Station on the Darling River in November 1867. Here, probably in the years before his birth, his father had seen a flock of these birds:

> . . . of over two miles in length rise from where they had been feeding on the seeds of the luxuriant grasses that came up after the flood waters had subsided (MacGillivray 1929).

As a boy he spent some time at Eddington Station in the Queensland Gulf country. Memories from his childhood were recalled in a paper read before the Field Naturalists Club of Victoria on 11th March 1901.

> Twenty years ago it was no uncommon sight to see these birds flying in to water in an unbroken succession of mobs from fifty to several hundreds each for two hours or more at a time from the plains in all directions. Nothing could be heard near the waterhole but the clatter and whirr of wings as each mob alighted near the water, each bird running down to the edge, dipping its bill once or twice, and then off again to the plains for the night (MacGillivray 1901).

He was at that early stage already an enthusiastic oologist, noting that he had:

> . . . frequently taken this bird's eggs over twenty-five years ago when resident in the district (MacGillivray 1929).

MacGillivray obtained his medical degree in 1890 from the University of Melbourne and practised in the western regions of Victoria until settling in Broken Hill near the area of his birth, where he practised from 1901 until his death in 1933. The commencement of his tenure coincided with the devastating drought of the late 1890s and early 1900s throughout the range of the Flock Bronzewing Pigeon from southern New South Wales to the Gulf of Carpentaria

(Frith 1982), which compounded the impacts of high stock numbers to cause widespread and irreversible pasture deterioration. The sheep population of the western division of New South Wales fell from 15.4 million in 1891 to 3.5 million after the drought (McKeon *et al.* 2004). There was a second severe drought episode in western New South Wales in the late 1920s. His ornithological writings reflect on the effects of drought on bird life with titles such as 'Drought Notes from Western New South Wales' in 1920, and 'Through a Drought-Stricken Land' in 1929. By this time there seemed ample evidence that drought and overgrazing had cast a spell of silent desolation on the "clatter and whirr of wings", and he wrote that:

> . . . we cannot get away from the fact that their (Flock Bronzewing Pigeon) numbers are rapidly diminishing, and it is only a question of time when the last of them will be sought for in vain (MacGillivray 1929).

However in May 1931, shortly before his death, came news of an invasion of Flock Bronzewing Pigeons into the north-west of New South Wales, and he subsequently travelled north from Broken Hill "to renew an acquaintance after an interval of fifty-five years" (MacGillivray 1932). MacGillivray was gratified to know that:

> . . . goodly numbers of this fine Pigeon still survive, though no longer in the vast flocks that once inhabited the plains and downs of north and central Queensland and similar areas in western and north-western New South Wales (MacGillivray 1929).

This biographical anecdote encapsulates much of the little that is known about this species: a gregarious, nomadic inhabitant of drought-prone rangelands, apt to make sudden and dramatic re-appearances after intervals of several decades, with a preference for the grassy downs of the semi-arid interior of the continent. These rangelands have received scant attention from conservation biologists, and the ecologies of many grassland dependent species, including the Flock Bronzewing Pigeon, have remained poorly described or unknown. This thesis aims to redress this deficiency.

Dispersive taxa which potentially interact with habitat and resources across large spatial scales present a challenge to researchers and conservation managers (Woinarski *et al.* 1992, Recher 2007). In northern Australia, flux of resources in space and time leads to dynamic and complex patterns of movement in many groups of organisms as they track resources through landscapes e.g. waterbirds inhabiting seasonal wetlands (Whitehead *et al.* 1992), frugivorous birds inhabiting rainforest patches (Price 2006), nectarivorous bats and honeyeaters inhabiting savanna woodlands (Palmer and Woinarski 1999, Woinarski *et al.* 2000) and granivorous finches inhabiting grassy savanna woodlands (Dostine *et al.* 2001). Conservation management of such fauna may entail management or protection of isolated and discrete patches of habitat to provide the full set of resources required over an annual cycle, or to allow for between year variability in the distribution of resources. The consequences of loss or degradation of critical habitat components can be dramatic and irretrievable, leading to endangerment, or severe range reductions in widespread organisms. Examples include the disruption of seeding patterns of perennial grasses by frequent fire leading to endangerment of the Gouldian Finch *Erythrura gouldiae* (Lewis 2007), and habitat loss leading to contraction in range of the Magpie Goose *Anseranas semipalmata* to tropical and sub-tropical wetlands (Woinarski *et al.* 1992).

Knowledge of the spatial strategies of mobile species underpins conservation management of these species (Soule *et al.* 2004). Despite the prevalence of species with dispersive movement behaviours in the Australian avifauna (Gilmore *et al.* 2007), details of the spatial strategies of the avifauna are poorly understood. This is especially so for those species that move opportunistically and seemingly unpredictably across landscapes in response to variable and erratic climatic conditions (Ziembicki and Woinarski 2007). Such conditions characterise the arid and semi-arid regions which occupy 70% of the land surface area of the Australian continent, where long intervals of drought are punctuated by periodic incursions of cyclonic and monsoonal depressions which trigger major biotic events across large geographic areas, leading to a 'boom-bust' economy for many species (Stafford-Smith and Morton 1990, Letnic and Dickman 2006, Robin *et al.* 2009).

There has been a long history of interest in the movement patterns of Australian land birds (Frith 1959, Carrick 1962, Frith 1962, Keast 1968, Nix 1976, Frith and Waterman 1977, Griffioen and Clarke 2002, Dingle 2004). Whereas knowledge of migration systems and movement patterns of northern hemisphere birds is supported by a network of ringing stations (Pilastro *et al.* 1998), data from long-term migration watch-sites, and long-term annual large-scale censuses (Koenig and Knops 2001), none of these are in place in Australia. With few exceptions, banding returns have generally been insufficient to provide detailed data on spatial and temporal movement patterns. For some species, principally game-birds, there is empirical evidence of distances moved between banding and band recovery (Frith 1959, Frith 1962, Frith and Waterman 1977). However, for most species, detailed understanding has largely been stymied by the low density of observers in inland Australia, negligible returns from bird banding programs, and the need for large-scale data on the patterns of habitat availability at temporal scales appropriate to the species.

The Flock Bronzewing Pigeon *Phaps histrionica* is a granivorous, ground-feeding bird of the perennial grasslands and arid riverine floodplains of northern Australia (Figures 1.1 and 1.2). Though a familiar element of these landscapes to many long-term residents, the details of their lives remain shrouded in mystery. Episodic appearances of large and spectacular aggregations, punctuating long periods of absence and obscurity, have contributed to its status as a charismatic enigma. The species is thought to be highly nomadic in response to large spatial and temporal variability in rainfall, and fluctuating and spatially unpredictable pulses of seed availability, but little is known of the spatial strategies employed by this species, or of the extent, timing or frequency of movements. It is not known whether movements are centred on a core range, or result in large-scale reconfiguration of the entire population. With limited evidence, Parker (1969) surmised that Flock Bronzewing Pigeons periodically pulse from core habitat.

> Presumably in good years this pigeon spills off the Barkly to occur in small numbers over most of the Territory (Parker 1969).

Frith (1982) speculated that their core habitat comprised the Mitchell grasslands of the Barkly Tableland and that occurrences elsewhere were short-lived and the result of nomadic movements after exceptionally good seasons. In contrast, though not referring specifically to pigeons, Nix (1976) proposed that birds within arid Australia undertake:

> . . . essentially random movements (in response to episodic rainfall) but with an underlying north-south bias which reflects the action of tropical and temperate weather systems at opposing seasons (Nix 1976).

The distinction between episodic pulsing from core habitat versus chaotic large-scale reconfiguration in response to spatial variability in rainfall will determine whether conservation actions should be directed towards building an adequate reserve network, or influencing diffuse land management practices.

The first scientific specimens of the Flock Bronzewing Pigeon were collected by the ornithologist John Gould in northern New South Wales in 1839 (McAllan 1996). Less than one hundred years later, and towards the end of decades of severe drought, ornithologists feared that the demise of the species was imminent (Berney 1928, MacGillivray 1929). MacGillivray (1932) commented that:

> Gradual overstocking of the country with sheep, cattle and horse, followed by devastating droughts, by depriving the birds of their natural shelter and food supply brought their numbers perilously close to the vanishing point, and bird lovers began to think they had shared the fate of the Passenger Pigeon of America (MacGillivray 1932).

Today, the future of the species cannot be considered as dire, but remains closely linked with the management of lands that remain largely uncultivated, but extensively occupied by pastoral enterprises. The black-soil plains which provide much of the habitat for this species are highly valued by the pastoral industry (Orr and Holmes 1984). The area of reserve network embedded within the pastoral landscape matrix is a minute fraction of suitable habitat and may not cater for year round resource needs, nor provide adequate contingencies for survival during widespread adverse conditions. Consequently, the conservation future of the species largely depends on informed sympathetic management of pastoral lands to ensure that the ecological requirements of this species are sufficiently met. This requires comprehensive understanding of the ecological requirements of the species and how these requirements interact with land management, underpinned by knowledge of the spatial strategy employed by this species, and strategies for adoption of management recommendations.

The Flock Bronzewing Pigeon is a useful exemplar of a far broader range of species that may have similar or comparable ecologies. This suite of species has been poorly served by conservation efforts to date. Though the Flock Bronzewing Pigeon probably occupies an extreme position on the mobility spectrum, their size and conspicuousness confer advantages for study over other species in this suite. This project forms part of the research program on conservation connectivity by the WildCountry Research Hub of the Fenner School of Environment and Society of the Australian National University. The program identifies connectivity at landscape, regional and continental scales as critical for effective conservation, and lists long distance biological movement amongst seven key ecological processes relevant to the conservation of biodiversity in Australia (Soule *et al.* 2004). The Flock Bronzewing Pigeon was selected as an extreme example of a dispersive species.

1.2 THE STRUCTURE OF THIS THESIS

Effective conservation of dispersive species such as Flock Bronzewing Pigeons will depend on comprehensive understanding of their ecological requirements and movement strategies, knowledge of the nature of impacts of land management on these requirements, and a capacity to ameliorate or nullify these impacts. The key research questions to be addressed by this thesis are:

(1) What types of vegetation communities are currently occupied by this species and were historically used by this species?

(2) What are the key food resources of this species and how do they vary seasonally and geographically?

(3) What are the past and ongoing impacts of land management on the abundance of key food resources of this species?

(4) What spatial strategies are employed by this species? Can core habitat be identified, and what circumstances lead to expansion from and contraction to core habitat? What is the nature and extent of movements linking patches of suitable habitat?

(5) What are the conservation management requirements of this species?

This thesis explores patterns of occurrence and habitat use of the Flock Bronzewing Pigeon at different spatial and temporal scales, and considers the impact of current land management on the abundance of food resources. Chapters draw on data of different types and from different sources to address the key research questions. Data on the patterns of occurrence of Flock Bronzewing Pigeons were gathered from (i) early published sources including accounts of explorers and pioneer ornithologists; (ii) national bird atlas schemes and data held by state fauna agencies; (iii) surveys of rangeland residents; (iv) field studies of populations; and (v) satellite tracking of individual birds. Some of these data were matched by descriptors of resource availability including (i) a time-series of interpolated rainfall surfaces at a continental extent from 1970 to 2008; (ii) a time-series of satellite-derived estimates of plant productivity at a continental extent from 2000 to 2007; and (iii) plot-based field data of resource abundance in 2006 and 2007. The effects of grazing and inter-annual variation in rainfall on food resources of this species were examined using two medium-term datasets on vegetation structure and composition in relevant land systems in northern Australia. The approach is designed to investigate multiple lines of evidence from different spatial and temporal scales, consistent with the hierarchical modelling framework proposed by Mackey and Lindenmayer (2001).

The approach is also descriptive and correlative rather than experimental or manipulative. There were no opportunities for large-scale manipulations: the large experimental units required were beyond the scope of this study, and all activities had to nestle within the operations of a working cattle station. A thesis time-scale may preclude the pivotal ecological drivers of a species that may pulse to a decadal-scale beat. There were considerable logistic challenges to be met including distance, inaccessibility of study sites in the wet season, the uncertainty of finding birds, the difficulties of capturing birds, and unknown factors such as the response of birds to capture and handling. For these reasons, this research explored a wide range of perspectives and methodologies.

Chapter 2 presents a review of the biology and ecology of columbid birds, summarises existing ecological knowledge of the Flock Bronzewing Pigeon with a review of historic and contemporary records, and discusses the conservation requirements of dispersive taxa.

The following nine chapters are divided into four sections. Chapters 3 and 4 review and analyse existing records compiled from a variety of data sources. In Chapter 3 generalised linear modelling is used to generate predictive spatial models of the distribution of Flock Bronzewing Pigeons using locality data compiled from various sources and a set of environmental predictors. Chapter 4 analyses spatial and temporal variation in the patterns of occurrence within this compiled dataset. Chapter 4 also examines rainfall patterns associated with a subset of records mostly from the ornithological literature, and asks what are the climatic features associated with reports of significant phenomena associated with this species.

Chapters 5 and 6 present results of community-based surveys of rangeland residents. This approach can be a valuable adjunct to research studies on spatial dynamics, and potentially provides a temporal perspective that is otherwise not available. Significantly, it allows for the participation of individuals who may subsequently be willing to adopt management measures for conservation of the species on their own land. Chapter 5 presents responses to ten questions on patterns of occurrence of the species within different temporal scales. Chapter 6 presents the results of monthly observations on Flock Bronzewing Pigeon abundance from a network of informants within the rangeland community, and asks how does this species respond to rainfall-driven variation in the distribution of resources within an eighteen month period? In particular the chapter seeks to understand whether populations periodically expand their range from core habitat, or undertake serial nomadic movements.

Chapters 7 to 10 comprise a body of field work conducted at a site in the Barkly Tableland in the Northern Territory. Specifically, in Chapter 7 I ask which plants provide the food for this species, in Chapter 8 I ask which parts of the landscape are preferred by Flock Bronzewing Pigeons, and in Chapter 9 I ask how do food plants and their seeds vary through space and time. Lastly, in Chapter 10 I report the results of a pilot study of the application of satellite telemetry to document movement behaviours of this species.

Chapter 11 comprises an analysis of two datasets on the effects of grazing and inter-annual variation in plant community composition from medium-term studies on relevant land systems in the Northern Territory. These include a five year study (2003-2007) of the botanical composition of sites with different pasture utilisation rates on Pigeon Hole Station in the Victoria River District, and a comparable three year study (2002-2003, 2006) of the botanical composition of sites with different pasture utilisation rates on Mount Sanford Research Station in the Victoria River District. In this chapter I ask whether there are links between grazing treatments and the abundance of known key food plants of the Flock Bronzewing Pigeon. Finally, Chapter 12 presents a synthesis of the results, a model of the dynamics of the species, and recommendations for further work.

The appendices include chapters on mass drinking behaviour and inter-annual variation in abundance which were referred to in the thesis but not included, notes on capture methods, and tabulated summaries of comments received from pastoral landholders in response to surveys in 2002/03 and 2005.

Figure 1.1 Flock Bronzewing Pigeons, Cunnamulla area, Queensland.

Photo by L. Hickson.

Figure 1.2 Flock Bronzewing Pigeons, Bedourie area, Queensland, August 2007.

Photo by A. Emmott.

Chapter 2: LIFE IN THE OPEN SPACES. ECOLOGY, ENVIRONMENTAL CONTEXT, AND CONSERVATION REQUIREMENTS

2.1 INTRODUCTION

This chapter presents a review of four principal themes. Firstly, I summarise the biology and ecology of the avian family Columbidae and the biology and ecology of the unrelated, but ecologically similar Pteroclidae (Sandgrouse). Secondly, I summarise existing ecological knowledge of the Flock Bronzewing Pigeon and provide a review of the early and contemporary literature. Thirdly, I discuss the main relevant environmental features of the arid and semi-arid rangelands, and lastly I discuss requirements for conservation of dispersive taxa.

2.2 TAXONOMY AND ECOLOGY OF COLUMBID BIRDS

The Flock Bronzewing Pigeon belongs to the avian family Columbidae, a large and homogeneous group known as pigeons and doves. The group is morphologically uniform, and ranges in body size from the diminutive Diamond Dove *Geopelia cuneata* of inland Australia and the Ground Doves *Columbina* of the Americas (~30 g) to the large fowl-like Crowned Pigeons *Goura* of New Guinea (>2 kg). Columbids are among the most successful avian families: they are cosmopolitan and widespread, occur in a diverse range of habitats in every region except Antarctica and the high arctic, and include 309 species in 42 genera (Baptista *et al.* 1997). The terms pigeons and doves have no strict taxonomic meaning, and are frequently used interchangeably for the same species, though smaller species tend to be known as doves, and the larger as pigeons.

The family includes five recognised sub-families (Goodwin 1983): Columbinae or typical pigeons (181 species); Gourinae or crowned pigeons of New Guinea (3 species); Treroninae or fruit-doves (123 species); Didunculinae or Tooth-billed Pigeon of Samoa (1 species); and Otidiphabinae or Pheasant Pigeon (1 species). The centres of diversity are Africa-Madagascar, the Neotropics and particularly Australo-papuasia with 76 species in 21 genera (Schodde 1997). Most species occur within tropical rainforests (Baptista *et al.* 1997). The taxonomic affinities of columbids are unclear. They are placed in the order Columbiformes with the Raphidae, the extinct dodo and solitaires, a group of specialised insular endemics. The Sandgrouse Pteroclidae were once thought to be columbiformes: evidence from DNA hybridisation now places pteroclids in the sub-order Charadrii with plovers, waders and gulls (Sibley and Ahlquist 1990).

Columbids are amongst the most recognisable of birds, with a compact body, short weak bill, short legs and neck, and small head, and well developed pectoral muscles. The flight muscles tend to be larger than in other avian groups and comprise 31-44% of the body weight (Baptista *et al.* 1997). They possess a bi-lobed crop and muscular gizzard, though the gizzard may be less developed in frugivorous species (Schodde 1997). The crop is an enlargement of the wall of the oesophagus, and permits rapid collection and storage of food. Adaptive advantages of this storage organ may include transport of food over long distances from feeding grounds to young, or minimising feeding time and maximising time available for searching for patchily distributed food resources (Wiens and Johnston 1987). Pigeons are unique amongst birds in that both sexes produce a high protein food for young known as crop-milk. The pituitary hormone prolactin stimulates cells in the crop wall to thicken and function as a gland. Nutrient rich cells are sloughed off and stored as crop-milk to be fed to young by regurgitation. High protein content of crop-milk facilitates fast growth of nestlings. In seed-eating pigeons the proportion of crop-milk in the regurgitated food declines with nestling age, and adults cease to feed crop-milk several days before the young fledge (Baptista *et al.* 1997). Pigeons are also unusual in their manner of drinking. Most birds drink by scooping water into the buccal cavity; pigeons and some Australian estrildid finches drink in a continuous draught by immersing the bill and sucking with a pumping action. The advantages of this drinking action may include minimising time spent in high predator risk environments, or the ability to exploit shallow water sources, such as puddles, or in fallen leaves, that may not be available to other birds. The food of pigeons is swallowed whole; seed-eating species do not extract seed kernels from enclosing capsules or husks, as do finches and parrots.

Columbids generally make little investment in nest building, and have not evolved cryptically coloured eggs. They lay 1-2 relatively small whitish eggs, and have a short incubation period and rapid nestling growth facilitated by the high protein content of the crop-milk. The young are altricial and nidicolous i.e. young are dependent on parents for food and remain in the nest after hatching. Fledglings leave the nest at 50-70% of the adult weight. This compression of the breeding cycle potentially allows for multiple broods within a breeding season (Gibbs 2001, Baptista *et al.* 1997). Some species are capable of precocious breeding. Many species perform aerial display flights, usually involving a combination of wing-clapping and a gliding descent with wings held in a V or dihedral shape above the body.

Pigeons generally have powerful flight and are highly mobile, and may commute long distances on a diurnal basis. Pied Imperial Pigeons *Ducula bicolor* nesting on off-shore mangrove atolls 16 km from the coast make daily foraging trips to mainland rainforests (Crome 1975); Speckled Pigeons *Columba guinea* fly 32-40 km daily from cliff roosting sites to foraging areas (Baptista *et al.* 1997). Pigeons exhibit a range of movement strategies; most are relatively sedentary, some have migratory movement patterns, whilst others are nomadic. The Australian Flock Bronzewing Pigeon *Phaps histrionica* reputedly exploits resource patches over vast spatial scales; the north American Band-tailed Pigeon *Columba fasciata* forms nomadic post-breeding flocks searching for acorn mast; the extinct Passenger Pigeon *Ectopistes migratorius* similarly formed vast flocks searching for spatially dispersed mast crops; and the Eared Dove *Zenaida auriculata* of semi-arid north-east Brazil migrates in huge numbers to breed and feed on resources which are spatially clumped and unpredictable in occurrence due to irregular rainfall (Bucher 1982).

Due to their powerful flight and dispersive abilities pigeons are excellent colonisers of oceanic islands, and subsequent speciation has led to a proliferation of endemic island forms, many of which are now threatened with extinction. Collar *et al.* (1994) list 56 pigeon species as Threatened, and 45 as Near-threatened; the more recent data of Walker (2007) estimates that 59 are Threatened, and 38 are Near-Threatened. Thus, about a third of all known extant columbid species face some degree of extinction threat. Few large bird families contain such a high proportion of threatened species. Twelve species of columbids are already extinct. All but two threatened columbid species inhabit tropical forests, and most of these (78%) are island species. The greatest causes of threats are habitat loss and fragmentation, hunting and alien predators (Walker 2007). The Passenger Pigeon *Ectopistes migratorius* of north America was once regarded as the most numerous bird in the world, but declined precipitously from 1870 to extinction with the last individual dying in Cincinnatti Zoo in 1914. The most feasible hypothesis for its rapid decline is that forest fragmentation passed critical thresholds for birds to locate patchy and aseasonal food resources, which required social facilitation to locate and exploit (Baptista *et al.* 1997, Gibbs *et al.* 2001).

The Australian columbid fauna includes 22 native species and three introduced species. Of these most are continental endemics, most occur in coastal and near-coastal forests and woodlands of the north and north-east, though they have radiated to occupy all habitats and wide ecological niches. Perhaps due to the relative absence of gallinaceous birds they have radiated to fill ecological niches occupied by these birds elsewhere. For example, the Partridge and Squatter Pigeons resemble partridges of the genus *Perdix*; and Spinifex Pigeons resemble Red-legged Partridges of the genus *Alectoris* (Frith 1982). The Flock Bronzewing Pigeon has ecological resemblances to Sandgrouse of the genus *Pterocles* in the family Pteroclidae.

Schodde (1997) acknowledged the lack of clarity in the infra-familial lineages of Columbidae, but nominated four principal columbid assemblages in Australia. These include the Columbini (typical pigeons and doves), Macropygiini (long-tailed pigeons), Phabini (Australo-Papuan bronzewings) and the Lopholaimini (Australo-Papuan fruit-pigeons). Fruit-pigeons in the large genera *Ducula* and *Ptilinopus* are obligate arboreal frugivores, and many species move widely between rainforest patches exploiting asynchronous patterns of food abundance: consequently these species have a requirement for large areas of intact habitat with high levels of patch connectedness (Price *et al.* 1999) and are threatened by habitat loss and fragmentation. The group known as bronzewings contains 9 species in four genera including Bronzewing Pigeons *Phaps* (3 species); Partridge, Squatter and Spinifex Pigeons *Geophaps* (3 species); Crested Pigeon *Ocyphaps* (1 species); and Rock Pigeons *Petrophassa* (2 species). All are ground-feeding species and feed on varying proportions of seed from grasses, herbs, and woody plants (Frith *et al.* 1974, Frith and Barker 1975, Frith *et al.* 1976, Crome 1976, Fraser 2000).

Within the Australian region two endemic island subspecies are extinct (*Columba vitiensis godmanae* and *Hemiphaga novaeseelandiae spadicea*), another critically endangered (*Chalcophaps indica natalis*) and another near threatened (*Geopelia placida papua*). One endemic island species is extinct (*Gallicolumba norfolciensis*) and another critically endangered (*Ducula whartoni*) (Garnett and Crowley 2000). No Australian mainland species of columbid has become extinct, though many species have declined in abundance. Franklin (1999) used reporting rates to analyse the patterns of decline of granivorous birds in the savannas of northern Australia: of eleven native columbid species four had declined and two had increased (Table 2.1). The four declining species occupied the upper end of the body size range. The generalised food habits of the increaser species Crested Pigeon *Ocyphaps lophotes* may explain its increase in range (Frith *et al.* 1974, Davies 1977, Reid 1996), as well as broad-scale changes to habitat and water availability associated with the appropriation of the rangelands by domestic stock.

Table 2.1 Eleven native granivorous columbid species of the savannas of northern Australia.

Species	Body Wt (g)	Change (Franklin 1999)	Conservation status (Garnett and Crowley 2000)
Diamond Dove *Geopelia cuneata*	33	No evidence	
Peaceful Dove *Geopelia striata*	41-66	Increase	
Spinifex Pigeon *Geophaps plumifera*	80-110	No evidence	*G. p. leucogaster* Near Threatened
White-quilled Rock Pigeon *Petrophassa albipennis*	100-150	No evidence	
Bar-shouldered Dove *Geopelia humeralis*	110-150	Possible increase	
Chestnut-quilled Rock Pigeon *P. rufipennis*	160	No evidence	
Crested Pigeon *Ocyphaps lophotes*	150-250	Increase	
Partridge Pigeon *Geophaps s. smithii*	160-250	Decline (ssp. *blauwii* rare, status uncertain)	Near Threatened
Squatter Pigeon *Geophaps s. scripta*	200-225	Decline (ssp. *scripta* only)	Near Threatened
Flock Bronzewing Pigeon *Phaps histrionica*	300	Decline	Near Threatened
Common Bronzewing *Phaps chalcoptera*	320-350	Decline	

2.2.1 The Pteroclidae: an ecological analogue?

On his first encounter with the pigeon in the Namoi valley in northern New South Wales the pioneer ornithologist John Gould noted a superficial resemblance between Flock Bronzewing Pigeons and a group of Old World species known as sandgrouse.

> I first met with this new and beautiful pigeon on the 2nd December, 1839, while encamped on the banks of the Mokai, a river which rises in the Liverpool range, and falls into the Namoi. I was strolling beside the stream at sunrise, when one of these birds rose from the water's edge, flew to the distance of forty yards, and again alighted on the ground, where it assumed much of the air and actions of a Sand Grouse (Pterocles) (Gould 1848, cited in Frith 1982).

Sandgrouse (Family Pteroclidae) are a homogenous group of two genera and 16 species with an Old World distribution in Afro-tropical, Palaearctic and Oriental regions. Their taxonomic affinity has been vigorously debated: they were formerly regarded as belonging to the order Columbiformes, partly on the basis of false information on their pigeon-like drinking behaviour, but are now regarded as having affinities with the Charadriiformes, or wader birds. de Juana (1997) placed the group in their own order Pterocliformes, between the Charadriiformes and Columbiformes. They are short-legged, short-necked, seed-eating birds of arid and semi-arid environments which demonstrate ecological adaptations which clearly echo those of Flock Bronzewing Pigeons. As such, they may constitute an ecological analogue for this species, and the known ecological information is summarised here to identify and understand adaptations to a common ecological setting. Much of this information is based on the studies of Maclean (1968) and the review of de Juana (1997).

The genus *Pterocles* was named from the Latin *pteron* or wing for the long, pointed wings possessed by members of the genus. This wing structure is designed for flight at high cruising speeds and is characteristic of birds with a way of life with a premium on high mobility (de Juana 1997). All but one species of sandgrouse drink regularly and commute long distances (as much as 80 km) between drinking sites and feeding areas. Drinking generally occurs in the cool of early morning to avoid overheating during the hotter part of the day, though a group of four species have crepuscular or nocturnal drinking habits. Different species have characteristic and precise times of arrival at water in relation to sunrise. For example, in the Kalahari Desert Namaqua Sandgrouse *Pterocles namaqua* drink 1-2 hours after dawn, and Burchell's Sandgrouse *P. burchelli* drink 2-2½ hours after dawn. Small flocks flying to water advertise by calling loudly and attract other birds to join the travelling flock. Many local common names for these species are onomatopoeic renditions of the flight call. At water, sandgrouse display caution, and may circle the watering site several times before settling on the ground distant from the water. They may land directly on the water surface and drink whilst floating. Drinking is completed within 5-10 seconds and they depart immediately. Synchronised mass drinking behaviour has been interpreted as allowing for exchange of information on the location of dispersed and unpredictable feeding areas (Ward 1972, Ward and Zahavi 1973).

Sandgrouse feed on small hard seeds of ephemeral plants gleaned from the ground surface. In general, the diet is characterised by low diversity of seeds taken at each locality, and a widespread preference for seeds of the family Fabaceae, which may be associated with the high protein content of these seeds. Seeds of grasses are rarely important. A study of the diet of Namaqua Sandgrouse in southern Africa revealed a preference for seed of annual plant species especially of the families Fabaceae and Aizoaceae. Full crops contained between 3,000 and 40,000 seeds (Lloyd *et al.* 2000). Other data suggest diet specialisation: in north Africa Spotted Sandgrouse *P. senegallus* fed exclusively on the seed of spurge *Euphorbia guyoniana* (Euphorbiaceae) (de Juana 1992).

Sandgrouse nest on the ground, usually in the open and rely on crypsis to avoid detection. They lay a single clutch of 3 cryptically coloured eggs. Incubation duties are shared by the monogamous pair with the female attending the nest during the day. Nest losses are high and estimated at more than 80% by small carnivores such as mongoose, which may have increased in abundance due to the removal of larger carnivores (Little *et al.* 1996). Chicks are precocial and feed on an adult diet soon after leaving the nest. Most losses of chicks are due to predation by birds such as corvids and raptors.

The movements of most species are not well known, though most are regarded as opportunistic or nomadic. The Pallas's Sandgrouse *Syrraptes paradoxus* is known for occasional irruptive movements from the steppes of central Asia to western Europe, perhaps in response to adverse conditions. The Namaqua Sandgrouse *P. namaqua* is regarded as a 'partial migrant' on the basis of seasonal differences in reporting rates in different parts of their range (Malan *et al.* 1994), though the factors underpinning these movements are unclear (Lloyd *et al.* 2001). Malan *et al.* (1994) proposed that migratory movements permitted the birds to track anticipated availability of seed between regions with different rainfall seasons: subsequent analysis suggested that the timing of migratory movements may involve complex interactions with bird nutrition and seasonal variation in nest predation pressure (Lloyd *et al.* 2001).

Gamebird populations in the Afro-tropical regions are regarded as being 'event-driven' and respond to patterns of fire and the frequency and intensity of rainfall (Crowe and Berry 1985). Long-term hunting records permitted an analysis of population fluctuations of Namaqua Sandgrouse and rainfall (Little *et al.* 1996) that demonstrated that peaks in abundance correlated with March rainfall and potentially seed abundance during the non-breeding (winter) season. Nomadic granivores, including the Namaqua Sandgrouse, required more substantial rainfall than resident insectivores to stimulate a population-wide breeding response (Lloyd 1999).

Most sandgrouse species are not of conservation concern: some species may have benefited from the addition of watering sites in arid landscapes and agriculture in marginal lands, though some species are subjected to harvesting from gamebird hunting, whilst others are pressured from intensification of farming practices particularly irrigated cropping.

The points of similarity between members of the Pteroclidae and Flock Bronzewing Pigeons are many as will be recognised in subsequent chapters. In brief, both are gregarious flock-forming granivores contending with high spatial and temporal variability in ephemeral food resources driven by erratic and variable rainfall.

2.3 THE FLOCK BRONZEWING PIGEON

The Flock Bronzewing Pigeon (also known as the Flock Pigeon or Flock Bronzewing) was formerly known as the Harlequin Bronzewing or Harlequin Pigeon (Frith 1982), due to the supposed resemblance of the black and white facial markings of adult males to facial masks worn by pantomime 'harlequins' of Italian or French theatrical comedy. The scientific name bestowed by John Gould in 1841 was *Peristera histrionica*, with the generic name from the Greek word for pigeon and the species name reflecting the theatrical attributes noted above. Flock Bronzewing Pigeons are plump medium-sized pigeons with a short rounded tail, short powerful legs and long-pointed wings unlike other bronzewing genera, and with relative wing length greater than the other members of the genus *Phaps* (Frith 1982). Sexes are dimorphic with the male slightly larger. The body plumage of the adult male is chestnut brown above and blue-grey below with distinctive black and white markings on the head and neck whilst the plumage of females is duller with less distinct mottled brown facial markings. Juvenile birds mostly resemble females, but with upperparts and wing coverts with pale fringes, giving a scalloped appearance (Figure 2.1). White spots on the tips of the primaries are visible in the folded wing. They are usually gregarious, and have a distinctive flight silhouette, and swift flight with deep continuous wing beats. Detailed descriptions of plumage characteristics are given in Frith (1982) and Higgins and Davies (1996).

Flock Bronzewing Pigeons are granivorous, ground-nesting birds associated with black-soil plains dominated by the perennial tussock-grass known as Mitchell grass (Frith 1982, Higgins and Davies 1996). They are most commonly observed during their morning and afternoon visits to water for drinking (Schmidt 1967, Fisher *et al.* 1972) during which they gather *en masse* and exhibit synchronised behaviour similar to that described for sandgrouse species in southern Africa (Maclean 1968, Ward 1972). Mass drinking behaviour in Flock Bronzewing Pigeons is described in detail in Appendix 1.

In Mitchell grasslands Flock Bronzewing Pigeons feed on seeds of annual herbs especially of plant families Euphorbiaceae, Boraginaceae, and Asteraceae, and seed of some annual grasses (Frith *et al.* 1976). Foods eaten in other habitats include seed of plant families Chenopodiaceae (Read 1991) and Euphorbiacae (Reid 1988). Seeds of perennial grasses are not prominent in the diet.

Females lay two whitish eggs in a simple scrape on the ground beneath shelter provided by perennial grass tussocks or shrubs (Frith 1982, McAllan 1996, Higgins and Davies 1996). There are historical records of dense colonial nesting involving several thousand birds (Reese 1931, Frith 1982); most recent reports are of isolated nests, and there are no recent accounts of large-scale nesting. Frith (1982) had not seen a mass breeding event. Within the range of the Flock Bronzewing Pigeon there were no small native predators and nest losses would have been low prior to the introduction of feral cats and foxes. These predators potentially contribute to nest losses and may limit the distribution of the species (Garnett and Crowley 2000). Aerial predators such as Black Falcons *Falco subniger* have been observed in company with flocks of Flock Bronzewing Pigeons (McAllan 1996), though data on predation rates or success is sparse. They have been recorded in the food of the Grey Falcon *F. hypoleucos* (Olsen and Olsen 1986) and a failed pursuit by a Peregrine Falcon *F. peregrinus* has been described (Read *et al.* 1996). Some losses to aerial predators occur when fledglings are disturbed from the nest by grazing stock. The movement patterns of Flock Bronzewing Pigeons are poorly known; they are assumed to be highly nomadic in response to shifting patterns of primary production driven by erratic and variable rainfall, and to pulse from core habitat to occupy marginal habitat (Parker 1969, Frith 1982).

Figure 2.1 Adult female, juvenile and adult male Flock Bronzewing Pigeons *Phaps histrionica*, Helen Springs Station, Barkly Tableland, NT.

Photo by M. Armstrong.

2.3.1 Review of published records

Historic and contemporary published records of the Flock Bronzewing Pigeon are reviewed in the following section. Localities mentioned in the text are shown in Figure 2.2.

Western Australia

In Western Australia Flock Bronzewing Pigeons were first recorded in June 1858 by surveyor F.T. Gregory who noted in his journal that near Mount Augustus the birds "congregate in flights sometimes of a thousand together" (Serventy and Whittell 1967).

Local resident Tom Carter contributed insightful ecological observations on Flock Bronzewing Pigeons in two short papers to the ornithological journal *The Emu* (Carter 1902, 1904). Carter noted that they were irregular visitors to the Pilbara coast and usually appeared in the aftermath of a "hurricane" (Carter 1904). In January 1901 Carter observed that:

> Enormous flocks of the pigeons were feeding on the freshly burnt ground, and about 8 am they began to water at the pool in countless thousands. The roar of their wings was like the noise of heavy surf breaking on the beach (Carter 1902).

Carter noted that their occurrence in large numbers was sporadic and speculated that patterns of rainfall across northern Australia resulted in large-scale reconfiguration of the population.

> Referring to Mr North's pamphlet on the decrease in numbers of this and other birds, may it not be accounted for in some measure by the birds following rains and feed to different parts of Australia, some year, perhaps, elapsing before they occur again in any particular locality (Carter 1902).

Their appearance in Western Australia at this time coincided with the height of a widespread and severe drought in eastern Australia (McKeon *et al.* 2004). In September 1927 a flock of sixteen was seen near Onslow (Serventy and Whittell 1967), but it was not until 1958 that substantial numbers were again reported in the Pilbara (Marshall and Drysdale 1962, Marshall 1965, Serventy and Whittell 1967), according to Frith (1982) in the wake of the abnormally wet year of 1956. Additional brief records for Western Australia are given in Mathews (1909) and Marshall (1966).

In summary, the published evidence suggests that aggregations of Flock Bronzewing Pigeons are rare events in Western Australia, but have occurred on at least two occasions in 1901 and 1958.

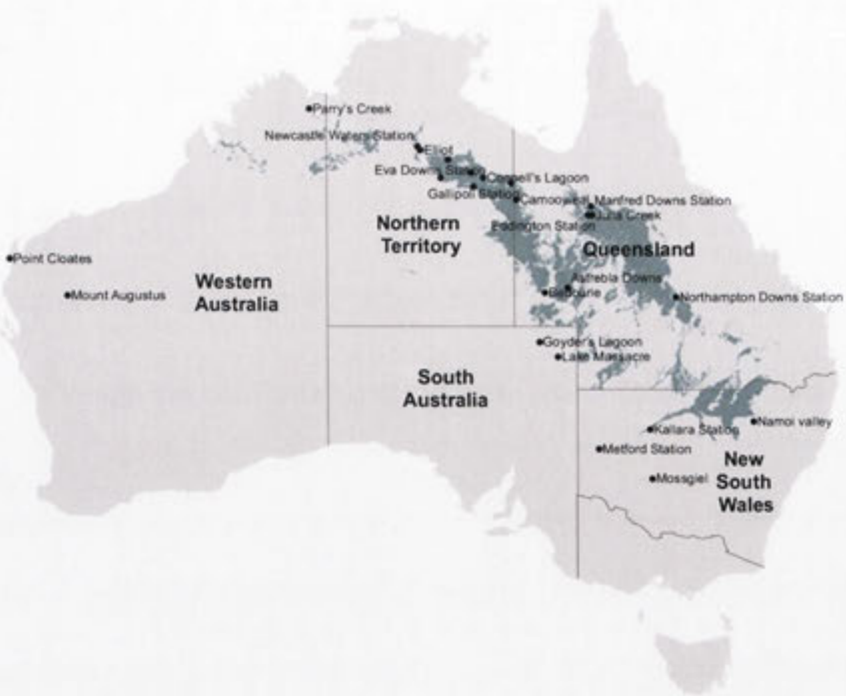


Figure 2.2 The distribution of selected localities mentioned in the text.

The distribution of grasslands dominated by Mitchell grass *Astrebla* spp. also shown.

Northern Territory

The explorer John McDouall Stuart undertook three attempts to cross the continent from south to north. On the second in 1861 he observed large numbers of Flock Bronzewing Pigeons on Newcastle Creek, on Newcastle Waters Station.

> I observed very large flocks of pigeons coming in clouds from the plains in every direction towards the ponds. Some time afterwards we saw them coming back and flying away into the plains as far as the eye can reach, apparently to feed (Hardman 1975, cited in Fleming *et al.* 1983).

On the third expedition the naturalist F.G. Waterhouse remained at Howell's Ponds on the northern boundary of Newcastle Waters while Stuart explored further north. Here, Flock Bronzewing Pigeons "daily passed in flocks of many thousands" (Waterhouse 1863, cited in Fleming *et al.* 1983). In 1872 John Lewis was contracted to run dispatches between Tennant Creek and Daly Waters during the construction of the overland telegraph line and later took up grazing rights on Newcastle Waters pastoral lease. He noted that:

> Sturt's Plain was alive with Flock Pigeons. From some distance they looked like clouds of smoke ascending here and there from different parts of the plains. Never before had I seen such numbers of feathered game (Lewis 1922, cited in Fleming *et al.* 1983).

Biological surveys of parts of Newcastle Waters in July 1982 revealed "only a handful" of Flock Bronzewing Pigeons at number 6 bore near Junction Reserve (Fleming *et al.* 1983).

In correspondence with F.L. Berney, H.A. Barnard reported that in February 1913 only three individual pigeons were seen west of Brunette Downs, and in June 1913 a small flock of eighteen were noted halfway between Anthony Lagoon and Brunette Downs (Berney 1928). In correspondence dated 20th April 1931 Reese (1931) refers to an undated observation of a large breeding event of Flock Bronzewing Pigeons on the Barkly Tableland "I have heard of the Flock-Pigeons nesting in thousands at Alroy, NT."

Pioneer pastoralist Charles Schultz of Humbert River Station in the Victoria River district took mobs of cattle to Queensland on the Barkly stock route on four occasions between 1935 and 1941. The month and year of the following recollection was not recorded. Schultz noted the familiar habit of Flock Bronzewing Pigeons arriving to drink at watering points in the late afternoon.

> Coming out of the Murranji, from about the Bucket waterhole right through Newcastle Waters there, as faaaar as the eye could see, there were flock pigeons. By God, they're good eating! They're all meat too, you know. I didn't have a shotgun so I had to shoot the buggers with a .22 rifle. I just sat on the side of the earthen tanks and shot them as they came in to water. The best feed I had was at Number 4 bore, near Eva Downs. I sat up on top of the bank with the .22, just before sundown. Gawd suffering Christ! I must have shot about twenty or twenty-five. I was running out of bullets! (Schultz and Lewis 1995).

In July 1958 Keith Williams noted large numbers of *P. histrionica* whilst travelling on the Barkly Highway 20 miles west of Camooweal.

> Flocks of Flock Pigeons were first noted soon after dawn, flying from north to south over the grassy plain. Flocks were estimated at roughly a hundred birds and hundreds of such flocks passed overhead. . . . We broke camp about 9.30 am and continued into the west where we found an aggregation of pigeons only a few miles from the campsite. Our vehicle disturbed them and they rose into the air in thousands, continuing to do so during the next mile of road. No further sightings of Flock Pigeons were made on that trip which lasted a month (Williams 1970).

In the mid-winter of 1962 Flock Bronzewing Pigeons were reported in "several thousands" on the Barkly stock route. The photograph accompanying the article shows a large flock in flight above an earthen turkey-nest dam on the Mitchell grass downs (Marshall 1965).

In late October of either 1965 or 1966 flocks of Flock Bronzewing Pigeons numbering between two to three hundred were seen arriving and departing at bores on Alroy Downs Station on the Barkly Tableland.

> After flying over the Turkey Nest water storage tank two or three times at a low height they would settle in a compact flock on the bank. Following a very brief stay for a drink they would fly off across the plain, never appearing to fly higher than about four feet from the ground, and disappear from sight very quickly (Schmidt 1967).

McEvey (1966) noted large numbers (i.e. flocks of up to 1,500) in April 1966 on Brunchilly Station, north of Tennant Creek. Four specimens were collected for diet analysis.

Frith (1982) asserts that Flock Bronzewing Pigeons remained numerous on the Barkly Tableland but were seldom reported in numbers elsewhere from the late 1950s until substantial widespread rainfall in northern Australia in 1967. Following this event dispersing birds were seen in the Alice Springs region, near Darwin (see below), and in the Simpson Desert. Frith (1982) records a large flock at an unspecified locality south of Katherine.

> Very large flocks were encountered to the west of the Stuart Highway south of Katherine and in that area I saw one such flock crossing the road. It was at least a kilometre from the front to the rear birds and the flock was 10 to 20 metres thick, flying on a front of perhaps 100 metres. There were many thousands in this mass of pigeons (Frith 1982).

Parker (1969) notes that frequent flocks of several hundred birds were seen over black soil grassland north of Gallipoli in August and September 1967. Parker also noted that information gleaned in 1967 from stock inspectors and station-workers indicated that the Flock Bronzewing Pigeon had been present in thousands for many years on the Barkly Tableland and that they disperse widely after years of good rainfall.

Flock Bronzewing Pigeons were recorded on three occasions at the Coastal Plains Research Station near Darwin between 1967 and 1971. All three records are from the late dry season on dry sedge-plains and rice-fields, and the most notable observation was up to 80+ between 29th August and 6th September 1969 (Crawford 1972). Thompson (1977) notes seven records for the Darwin area between March 1974 and December 1976, with the most notable being a flock of 26 near Holmes Jungle on 2nd September 1974.

Relatively few Flock Bronzewing Pigeons were recorded during biological surveys of Connell's Lagoon Stock Reserve in June 1982 (numbering less than a hundred) (Johnson *et al.*

1982) and Junction Stock Reserve and Newcastle Waters pastoral lease in July 1982 (Fleming *et al.* 1983).

During surveys of waterbirds on ephemeral wetlands on the Barkly Tableland following widespread heavy rain in February 1993, Jaensch recorded large numbers of Flock Bronzewing Pigeons on Brunette Downs Station.

> In December 1993 73,000 of probably 100,000 bronzewings were counted during their daily mass movements around the Lake Sylvester system (Jaensch 1994).

Additional records of small numbers of Flock Bronzewing Pigeons at various localities in the Northern Territory are provided by Ingram (1907), Rhodes (1944), Condon (1945), Marshall (1966), Parker (1969) and Boekel (1980).

In summary, most reports of Flock Bronzewing Pigeons in the Northern Territory are centred on the Mitchell grasslands of the Barkly Tableland. Whilst the historic record is sparse, these observations span the width of the Barkly Tableland, occur at periodic intervals, and include contemporary observations of very large numbers (e.g. Jaensch 1994). There is evidence of significant aggregations, presumably following extended recruitment episodes, in 1930, 1958, 1967 and 1993. Interestingly, there are few records for the intervening years between 1967 and 1993, and surprisingly no records of the consequences of the above average rainfall years in the mid-1970s.

Queensland

The first European records of Flock Bronzewing Pigeons in Queensland were during the Charles Sturt expedition of 1844-46 (McAllan 1996). In January 1845 Sturt and Browne saw Flock Bronzewing Pigeons as they travelled north-west into southern Queensland towards Stokes Range. In April 1845 the naturalist John Gilbert saw Flock Bronzewing Pigeons rising in flocks from burnt grass in the Burdekin valley, and later in June 1845 on the Mitchell River pigeons were seen in "countless numbers" in flocks so large that the noise they made "resembled the roar of distant thunder" (Chisholm 1945).

Berney (1928) catalogues his personal records on Flock Bronzewing Pigeons and others acquired in an attempt to assess their current conservation status. In 1882 Wray reported "tens of thousands" on the Georgina in far south-west Queensland. In 1886 after a series of dry years they:

> . . . came in thousands to Northampton Downs, and later nested everywhere on the open country . . . sitting birds kept bustling out with a rattle of wings from their nest-sites every few yards as one rode across country (Berney 1928).

In subsequent years there were relatively few records until August 1901, when he saw flocks described as "immense" on Manfred Downs in the Flinders River catchment, north-west Queensland. His last personal record of the species is of a single bird in September 1913 west of Hughenden. Berney concludes that Flock Bronzewing Pigeons had suffered a precipitous decline from 1901. "After 1901 the number of the Flock Pigeon fell in a manner that is nothing less than tragic." The severe drought of 1900/1901 triggered widespread land degradation and the collapse of stocking rates (Letnic 2007).

MacGillivray (1901) described Flock Bronzewing Pigeons as once being more numerous than any other bird inhabiting the fertile downs of the Gulf country. In the 1870's at Eddington station in the Gulf country:

> . . . it was no uncommon sight to see them flying in to water for two hours in the morning and evening in a succession of flocks that were almost continuous and coming from all parts of the plains (MacGillivray 1929).

Subsequently overgrazing and drought bared the plains such that they "afforded neither food nor shelter for the birds". Following substantial rainfall in central Queensland in 1930 Flock Bronzewing Pigeons were reported in flocks estimated to number 20,000 and 80-100,000 (MacGillivray 1932).

Reese (1924) reported that Flock Bronzewing Pigeons had been seen, without specifying a date, at Bedourie in far south-west Queensland "literally in millions".

In September 1967 great flocks were seen at the lignum channels between Birdsville and Bedourie in south-west Queensland; in October 1968 large numbers were seen from south of Bedourie to Boulia (Williams 1970). In December 1990 an estimated 100,000 Flock Bronzewing Pigeons were seen at bore number 2 on Astrebla Downs National Park (Stewart and Gynther 2003); in June 1994 at least 15,000 were seen drinking at Spellery Creek in the Julia Creek area (Andrew and Eades 1994). In August 2007 very large aggregations were reported in the Bedourie area of south-west Queensland (Forsyth 2007).

In summary, there are at least six accounts of major aggregations of Flock Bronzewing Pigeons in Queensland in the published record, i.e. 1901, 1931, 1967-1968, 1990, 1994 and 2007.

South Australia

Flock Bronzewing Pigeons were observed in "tens of thousands" in October 1861 near Lake Massacre on the McKinlay expedition to search for the lost trans-continental explorers Burke and Wills (Cleland 1937). The naturalist and explorer Samuel White despatched eggs of Flock Bronzewing Pigeons to John Gould collected from nests on sandhills around Lake Hope in late 1863 (Parker 1980).

Some details from early last century are provided by L. Reese, a resident of Minnie Downs station north of Marree in the far north-east of South Australia, in correspondence published in the ornithological journal *The Emu* (Reese 1924, 1927, 1931). Reese (1924) noted that Flock Bronzewing Pigeons were occasional visitors to the region; small flocks were noted in October 1926 (Reese 1927); and nesting observed in late 1930 and early 1931 (Reese 1931). Large numbers were present along the edge of the flood waters of Goyders' Lagoon from early 1931 (Reese 1931) to early 1932 (Anon 1932). Goyder's Lagoon had been filled by flood waters from the Diamantina River. In September 1931 Flock Bronzewing Pigeons were also recorded from Moolawatana station in the Lake Frome district (Anon 1932); numbers were also seen over an extensive area of the far north-east of South Australia (McGilp 1932).

An influx of Flock Bronzewing Pigeons into the far north–east occurred in late 1992 and small numbers were observed in the following years (Read *et al.* 1996). Additional records of Flock Bronzewing Pigeons particularly for the years 1988 and 1989 are given in Fraser (1990). In summary, large aggregations of Flock Bronzewing Pigeons in South Australia are rare and have been reported in 1861, 1931 and 1992.

New South Wales

The occurrence of Flock Bronzewing Pigeons in New South Wales has been reviewed in detail by McAllan (1996), and the subsequent discussion draws heavily from this source. The ornithologist John Gould collected the first specimens of the species from the Namoi valley in northern New South Wales in December 1839. The naturalist John Gilbert also witnessed large flocks of Flock Bronzewing Pigeons in the lower Namoi valley later in April-March 1844, and observed that some were nesting. It is unclear whether the grasslands of the Namoi valley provided high quality habitat for Flock Bronzewing Pigeons. This question has been addressed previously by Frith (1982) and McAllan (1996). McAllan (1996) contended that "It would seem that Flock Bronzewings may also have been regular visitors to the Lower Namoi, especially in view of later observations from the area." The paucity of the historical record prevents distinguishing between three hypotheses on their occurrence in the southern portion of their former range: (i) that Flock Bronzewing Pigeons were permanent residents, (ii) that Flock Bronzewing Pigeons were regular seasonal breeding migrants, or (iii) that Flock Bronzewing Pigeons were irregular migrants and responded opportunistically to infrequent favourable climatic conditions. Hypothesis (iii) appears the most likely. The floodplains of the Namoi have now been cleared for intensive agricultural development, particularly for cotton production (Arthington 1996).

The meat of native game such as wild pigeon subsidised the food stores of exploration parties, including that of Charles Sturt in north-western NSW in 1844-46. On 17th January 1845 Sturt noted:

> We had flushed numerous pigeons as we rode along, and flights came to the water while we stopped, but were not treated with same forbearance as the duck. We shot two or three, and capital eating they were (Sturt 1849, cited in MacAllan 1996).

There are frequent mentions of Flock Bronzewing Pigeons in the various expedition accounts, noting aggregations at water of more than 10,000 birds; attempts at capture using horsehair snares laid near water; observations of feeding on the seed of "rice grass"; and an apparent rapid and complete exodus following breeding.

In 1864 Flock Bronzewing Pigeons were extremely numerous on parts of the Hay Plain in central New South Wales. North (1913) published a letter from collector K.H. Bennett who noted that when this part of the country was first occupied Flock Bronzewing Pigeons were found in "countless multitudes", and that fledged birds were susceptible to predation by raptors including Black Falcons (*Falco subniger*) after being flushed from the ground by flocks of sheep. They appeared in smaller numbers on several subsequent occasions, but were not seen at all in the 8 or 9 years prior to May 1889.

MacGillivray (1929) referred to an observation by his father in the 1860s from Killara Station on the Darling River near the Paroo overflow.

> . . . a flock of over two miles in length rise from where they had been feeding on the seeds of the luxuriant grasses that came up after the floodwaters had subsided (McGillivray 1929).

MacGillivray (1932) recounted details of an influx of Flock Bronzewing Pigeons to Hewart Downs Station, in the north-west of New South Wales in 1931. The birds had nested by September, and numbers were greatly reduced by April 1932. The next major incursion in north-west New South Wales occurred from December 1992 to mid 1993 (McAllan 1996). About 2,000 Flock Bronzewing Pigeons were seen in early June 1993 near Metford Station west of Wilcannia (McAllan 1996, Andrew and Eades 1993).

2.3.2 Interpretation of published records

Years identified in the published historic record are listed in Table 2.2. There appear to be synchronous responses across states at approximately 30 year intervals. The mean interval between major aggregations is 26 years. This is probably a reflection of both the ecology of the species and the fragmentary nature of the historic record.

Table 2.2 Years of reports of notable aggregations of Flock Bronzewing Pigeons from the published record.

Sources: 1 Carter (1902), 2 Carter (1904), 3 Serventy and Whittell (1967), 4 Marshall (1965), 5 Marshall and Drysdale (1962), 6 Fleming *et al.* (1983), 7 Reese (1931), 8 Williams (1970), 9 Frith (1982), 10 Parker (1969), 11 Jaensch (1994), 12 Berney (1928), 13 MacGillivray (1932), 14 Stewart and Gynther (2003), 15 Andrew and Eades (1994), 16 Cleland (1937), 17 Reese (1931), 18 Read *et al.* (1996), 19 North (1913), 20 McAllan (1996).

WA	NT	Qld	SA	NSW
	1861[6]		1861[16]	1864, 1860s[19]
1901[1,2]		1901[12]		
	1930[7]	1931[13]	1931[6,17]	1931[13]
1958[3,4,5]	1958[8]			
	1967[9,10]	1967, 1968[8]		
		1990[14]		
	1993[11]	1994[15]	1992[18]	1992, 1993[20]

Published references on temporal patterns of occurrence are sparse, and biased towards historical accounts from the southern portion of their original range. Occurrences are spasmodic and associated with heavy rainfall after a period of drought (MacGillivray 1932, McAllan 1996). Flock Bronzewings were mostly temporary visitors and in three reports stayed for "several months" (North 1913), from May to following mid-April (McAllan 1996), and from May to at least the following March (MacGillivray 1932). Published records of breeding events of Flock Bronzewing Pigeons are also relatively sparse, and largely confined to the southern portion of their original range in western New South Wales. There are anecdotal and perhaps to some extent apocryphal references describing the size and density of nesting areas (Morse 1922, Marshall and Drysdale 1962, Rolls 1994).

> Other people have told of sheep camping in nesting areas and walking away in the morning with the yellow yolk, and the white shells, clinging to their woolly hides (Marshall and Drysdale 1962).

> Flock Bronzewing Pigeons fed there in huge numbers. They nested on bare ground between the grass clumps, one bird sitting a few centimetres from the next. Oldtimers tell of sheep's legs yellow with broken yolk (Rolls 1994).

Breeding events of the scale inferred by the descriptions of early observers have not been reported since prior to 1900. Subsequent breeding events are either on a substantially smaller scale or for whatever reason remain unreported. In the early 1930s breeding was reported to have occurred from central Queensland (locality not specified in MacGillivray (1932)), through the Channel Country of south-west Queensland (McGilp 1932) and into north-west New South Wales (MacGillivray 1932). There was a similar, though apparently smaller scale, event in the early 1990s (McAllan 1996).

Several early observers reflected on Flock Bronzewing Pigeon population declines in their area. For example, in the lower Lachlan district of New South Wales Bennett (1891) noted that:

> Amongst those that have entirely vanished may be mentioned *Phaps histrionica* . . . A few stragglers of *Phaps histrionica* were here in the year 1880, but none have been seen since (Bennett 1891).

Other species listed as locally extinct by Bennett (1891) include Squatter Pigeon *Geophaps scripta*, Plains-wanderer *Pedionomus torquatus*, and Crested Bellbird *Oreoica guttturalis*. All are ground foraging, mainly granivorous species susceptible to disturbance of ground layer vegetation (Crome 1976, Baker-Gabb 1988). The cause of these local extinctions was identified as pasture degradation by sheep grazing.

> There can, I think, be little doubt, but that in most cases this disappearance is due to the occupation and stocking of the country with sheep, whilst the prevalence of the domestic cat (gone wild) has doubtless in some cases proved another factor. In former years the whole of these vast plains were covered with a dense mass of vegetation in the shape of dwarf saltbush, herbaceous plants and grass, affording at the same time a safe cover, and a plentiful supply of food in the large quantities of their various seeds. For many years past, this state of things has been entirely changed by stocking with sheep, and as arule the country is bare, or at best affording but a scanty covering and an equally scanty supply of food (Bennett 1891).

> History relates that before the advent of sheep, they at times came here [the Moree district] in thousands. One old identity informed me that during the eighties 'they were breeding in such numbers in his horse paddock that he could have filled a washing tub with eggs' (Morse 1922).

> It is remarkable that, with so many people travelling over the country that should still hold the Flock Pigeon, I never hear of any being seen. The theory is that the stocking of their country with sheep has caused the Flock Pigeons to disappear, but there must be plenty of room for them in other parts (Brenan 1927).

There were genuine concerns in the first few decades of the 1900s that the species was facing imminent extinction (Berney 1928, MacGillivray 1929, McGilp 1932): these concerns were not allayed until after substantial widespread rainfall ended a prolonged drought and large numbers of birds reappeared in central Queensland (MacGillivray 1932).

2.3.3 Current conservation status

Populations of the Flock Bronzewing Pigeon are believed to have diminished from the pre-pastoral era due to the direct and indirect effects of pastoralism (Frith 1982). The Flock Bronzewing Pigeon vacated large areas of its range soon after the arrival of stock: the pattern of range contraction largely mirrors the historical pattern of settlement and pastoral development across the continent. They have largely vacated parts of their former range in eastern Queensland and western New South Wales, where they are listed as Endangered (Table 2.3), but still make occasional forays into the far north-west of the latter state (McAllan 1996).

Causes of this decline may include habitat degradation due to overgrazing and drought (MacGillivray 1932, Frith 1982); the elimination of Aboriginal burning practices in native grasslands (Franklin 1999, Franklin *et al.* 2005); and susceptibility to introduced predators in concert with suppression of the sole top-order predator (Garnett and Crowley 2000). Contemporary patterns of fire in Australia differ from those under pre-pastoral Aboriginal occupancy (Russell-Smith *et al.* 2007). Throughout much of Australia, including the Mitchell grasslands of the Barkly Tableland, fire has largely been eliminated from pastoral landscapes either by direct suppression by managers, or the removal of fuel loads by herbivores. Fire is used as a tool on conservation lands to generate habitat heterogeneity at appropriate scales to benefit native wildlife: on pastoral lands burning forage which might otherwise be available during a drought is regarded as a waste of a valuable resource. The ecological release of secondary predators by control of large predators can result in changes to prey populations. The removal of the Dingo is implicated in the collapse of populations of marsupial species (Johnson *et al.* 2006). Garnett and Crowley (2000) suggest that the area of decline of Flock Bronzewing Pigeons correlates with the distribution of the introduced fox. Dingos are actively controlled in lands used for sheep production, but are tolerated to some extent in lands used for cattle production.

The Flock Bronzewing Pigeon is one of a suite of granivorous bird species in northern Australia which exhibit similar patterns of decline, tentatively attributed to the collapse of Aboriginal burning regimes in pastoral lands (Franklin 1999). Most threatened bird species of tropical savannas are ground-foraging granivores (Woinarski 1993); analysis of the ecological traits of declining and non-declining granivorous birds indicated that ground-foraging, obligate granivores were most at risk (Franklin 1998). Worldwide, there is a common set of management issues in grasslands: habitat loss, fire suppression and shrub encroachment have led to disruption of natural processes, and extirpation or endangerment of bird species (see reviews in Goriup 1988, Brennan and Kuvlesky 2005).

Table 2.3 Conservation status in states in which it is listed in relevant legislation, in the Action Plan for Australian Birds (Garnett and Crowley 2000) and in IUCN Red List (2008).

Source: Clayton *et al.* (2006).

State	Listing	Conservation Status
New South Wales	Threatened Species Conservation Act (1995)	Endangered
Northern Territory	Territory Parks and Wildlife Act (2000)	Near Threatened
South Australia	National Parks and Wildlife Act (1972)	Vulnerable
Commonwealth	Environment Protection and Biodiversity Protection Act (1999)	Not listed
	Action Plan for Australian Birds (2000)	Near Threatened
	International Union for Conservation of Nature Red List (2008)	Least Concern

The species is still periodically and patchily common in parts of the semi-arid tropics and subtropics (Garnett and Crowley 2000); its stronghold is believed to include the Mitchell grasslands of the Barkly Tableland in the Northern Territory (Parker 1969, Frith 1982).

2.4 ENVIRONMENTAL CONTEXT

The arid and semi-regions of Australia are characterised by low nutrient soils, subdued landscape relief, and high year to year variability in rainfall (Stafford-Smith and Morton 1990). European settlement of Australia's rangelands proceeded rapidly in the absence of knowledge of grazing systems appropriate in regions of low but highly variable rainfall. Over 3.2 million km^2 of rangelands (43% of area of Australia) are used for grazing, predominantly on natural pastures. Much of this area has been degraded to some extent (McKeon *et al.* 2004).

Pastoral settlement proceeded rapidly across the continent in the footsteps of early exploration of the Australian interior. In 1835 the explorer Sir Thomas Mitchell led an expedition to follow the course of the Darling River in western New South Wales to the vicinity of the present township of Menindee on the lower Darling. By 1841 squatters had occupied land along the lower Darling, and by 1858 all the watered frontages on the river had been taken up (Lunney 2001). Pastoral lands in central west Queensland were occupied in 1860-1880, and pastoral lands of the Barkly in the Northern Territory were occupied in 1880-1890. The trans-continental expedition of Robert O'Hara Burke and William John Wills departed from Menindee in late 1860 in a doomed attempt to reach the northern coastline. In a subsequent attempt to locate the lost explorers in 1861 William Landsborough touched on the eastern edge of the Barkly Tablelands. Within a few years in 1865 the area along the Georgina River was stocked with sheep for a few years before abandonment forced by drought and distance from markets. In the 1870s there was renewed interest in these lands and in 1882 the South Australian government auctioned leases which led to the establishment of Alexandria Station in the eastern Barkly and by the mid 1880s most of the large pastoral enterprises on the Barkly Tableland had been established (Holt and Bertram 1981).

Pastoral settlement invariably focussed initially on the better watered productive lands used by Aboriginal people who were soon displaced to marginal lands or made dependent on pastoral settlements (Letnic 2000). Traditional methods of land management using fire to facilitate hunting or manage vegetation communities were replaced by management strategies driven by export wool markets, and insensitive to landscape fragility or an awareness of the effects of extreme climatic variability. Early stocking rates proved to be unsustainable: historical patterns of livestock numbers usually rise to a peak in the years after settlement then crash during a period of severe drought but fail to recover to previous levels (State of the Environment Advisory Council 1996).

Episodes of severe land degradation have occurred repeatedly throughout the period of settlement. McKeon *et al.* (2004) list 17 examples of regional landscape degradation and review the causes and consequences of eight episodes. In each episode excessive grazing and climatic variability interact to cause loss of desirable perennial grasses and shrubs. Common factors associated with degradation episodes include (i) rise in livestock numbers, (ii) period of high rainfall prior to droughts, (iii) government policy to ensure land was fully stocked, (iv) over-expectation of carrying capacity, (v) economic or logistic inability to destock, and (vi) amplification by drought of degradation processes already occurring. Degradation results in loss of desirable perennial species, loss of soil cover and structure, infestation by woody weeds and loss of management options such as firing to assist in recovery of degraded pasture.

Inappropriate land management in the early phase of pastoral development resulted in degradation of vegetation, irreversible loss of productivity, and loss of biodiversity. The degradation episode in the western division of New South Wales in the 1890s culminated in the extreme and widespread drought of 1902 (known as the Federation Drought), brought collapse of the sheep population from 15.4 million in 1891 to 3.5 million after the drought, and pasture changes including removal of Mitchell grass and saltbush, and increases in unpalatable species such as wire grass and copper burrs (McKeon *et al.* 2004). Degradation processes prior to this drought contributed to a much depleted landscape by the early 1890s, and the loss of 24 species of mammals (Lunney 2001). These extinctions were part of a pervasive process throughout the Australian arid zone, resulting in the highest rate of mammal extinction in the world in the last 200 years (Morton 1990). Analysis of the ecological attributes of the extinct and declining fauna identified that species feeding on grasses and herbs and/or seeds, inhabiting grasslands, shrublands and woodland, and within the medium weight range were most at risk (Lunney 2001). The causes of this faunal collapse include interactions between land degradation caused by excessive grazing, the collapse of Aboriginal burning regimes, and the effects of introduced predators.

Most of the grassy woodlands and grasslands of northern Australia have been grazed for between 100 and 150 years, but remain largely structurally intact and thus globally significant (Woinarski *et al.* 2007), and thus far have been spared the catastrophic faunal declines of temperate and arid Australia (Recher and Lim 1990), though evidence is now accumulating of declines in some faunal groups including granivorous birds (Franklin 1999) and mammals (Woinarski 2000).

Tussock grasslands known as Mitchell grasslands are a distinctive biogeographic entity within the tropical savannas of northern Australia and constitute an important grazing resource for the pastoral industry (Orr and Holmes 1984). Mitchell grasslands take their name from the explorer Sir Thomas Mitchell who collected the first specimens of the dominant perennial grass *Astrebla*, and recognised the grazing potential of these grasslands.

> Here was an almost boundless extent of the richest surface still uncultivated and unoccupied by man. A great reserve provided by nature for the extension of his race (Mitchell 1835, cited in Orr and Holmes 1984).

Within 70 years the “almost boundless extent” was fully occupied by pastoralists and their stock.

Mitchell grasslands cover an area of 320,000 km^2 in an extensive arc from the Kimberley region of Western Australia, through the Northern Territory and central Queensland and parts of northern New South Wales, on heavy clay soils between 250-550 annual rainfall isohyets where summer rainfall is dominant (Orr and Holmes 1984). The largest area of 215,000 km^2 occurs within Queensland, with 78,000 km^2 within the Northern Territory and smaller areas in Western Australia and New South Wales. These grasslands occur on two landforms, the almost treeless gently undulating downs on Cretaceous sediments in central and northern Queensland and the Barkly Tableland in the Northern Territory, and on alluvial plains along major river systems in southern Queensland. In good condition they are dominated by tussocks of the perennial grass *Astrebla.* The perennial grass tussock forms the basic unit of the pasture: under favourable conditions the basal area of *Astrebla* tussocks averages 4-5% of the pasture but declines under high pasture utilisation and drought. Interstitial areas between tussocks are occupied by annual grasses and annual and perennial forbs. The composition of the inter-tussock community is determined by the summer dominance of rainfall, and the inter-annual variability in rainfall (Everist and Webb 1975). Drought reduces the survival and basal area of perennial grasses which allows a short term response to rainfall by annual or ephemeral species; extended periods of good rainfall promotes biomass of perennial grasses by increasing seed set, seedling survival and increase in basal area (Orr 1981). Most ecological research in Mitchell grasslands has focussed on pasture management, and the populations dynamics of the dominant perennial species in relation to grazing and climate (Orr 1975, Orr and Holmes 1984, Orr *et al.* 1986, Orr and Phelps 1994).

Mitchell grasslands are generally regarded as resilient because of the low risk of soil erosion and the resistance of tussocks to drought and grazing (Orr and Holmes 1984). Moderate grazing may be required to maintain community stability in Mitchell grasslands in the absence of regular burning (Everist and Webb 1975). Mitchell grasslands have only recently received the attention of conservation biologists (Fisher 2001) and early pronouncements on the benign nature of grazing seem premature. There is evidence of deterioration, and replacement of perennial grasses by annual Flinders grasses in the Barkly (Holt and Bertram 1981) and Queensland (Scanlan and O'Rourke 1982). Regional rangeland condition surveys indicate the percentage area of Mitchell grasslands in deteriorating or degraded condition varies from 22% in the Barkly region of the Northern Territory, to 30% of the northern rolling downs of Queensland, to 70% of the stony downs and ashy downs of Queensland (Tothill and Gillies 1992).

2.5 CONSERVATION REQUIREMENTS

The Flock Bronzewing Pigeon may have been the most numerous bird in Australia prior to settlement (Lindsey 1995). Descriptions of encounters with this bird by early observers are almost invariably of very large numbers and replete with adjectives such as 'immense', 'countless' and 'prodigious' (see examples in section 2.3.1). Within decades of these encounters these abundant flocks had vanished from the southern and south-eastern portion of their original range and their grassland habitats transformed by agriculture. This process of northward range contraction is demonstrated by several other taxa, some of which were previously widely distributed throughout southern Australia, including Magpie Goose *Anseranas semipalmata*, Bush Stone-Curlew *Burhinus grallarius*, Red-tailed Black Cockatoo *Calyptorhynus banksii* and Australian Bustard *Ardeotis australis* (Woinarski *et al.* 2007). The demise of Flock Bronzewing Pigeon populations in temperate areas is mirrored by the catastrophic collapse of the mammal fauna in western New South Wales, which has been attributed to over-grazing and land degradation by sheep (Lunney 2001). Within Australia 19 vertebrate species have become extinct, and a further 10 species are extinct on the mainland (Soule *et al.* 2004). Only one mainland bird species has become extinct: the Paradise Parrot *Psephotus pulcherrimus* of the grassy woodlands of south-east Queensland. The causes of extinctions and population declines of the Australian vertebrate fauna involve disruption of the landscape linkages and extensive natural processes (Soule *et al.* 2004) which allowed the persistence of these species, though in most cases the exact causes are difficult to specify, and restorative action difficult to implement. The consequences of disruption of landscape linkages are discussed for three bird species in Australia: Long-billed Corella, Magpie Goose and the Gouldian Finch.

Prior to pastoralisation the Long-billed Corella *Cacatua tenuirostris* occupied grassy woodland habitats in south-eastern Australia, where the fleshy subterranean tubers of the Yam Daisy *Microseris lanceoloata* provided much of the winter food (Emison *et al.* 1994). This plant was abundant in the friable soils of the inter-tussock spaces of the perennial grassland community maintained by periodic burning and low intensity grazing by native herbivores. These grasslands have been transformed by sheep and cattle and are dominated by less palatable perennial grasses and introduced pasture species. The growth habit of *M. lanceolata* rendered it vulnerable to grazing: it is now rare and persists only in remnant refuges. From the mid 1800s *C. tenuirostris* declined to remnant populations primarily in south-western Victoria due to habitat degradation and loss of primary native foods. However, from 1950 there has been a population resurgence and range expansion which has been attributed to control of rabbit populations by the myxoma virus (Emison *et al.* 1994), and agricultural practices which have provided alternative sources of food.

The Magpie Goose *Anseranas semipalmata* is an iconic species of the wetlands of northern Australia, but was formerly abundant in southern Australia. It has been the focus of 30 years of ecological research due to its abundance and importance to tourism and for recreational and traditional harvest. Habitat suitability of breeding swamps vary depending on the timing and extent of wet season rainfall, and geese undertake an annual chaotic redistribution of breeding sites (Whitehead *et al.* 1992). Geese build floating nests of sedges and aquatic grasses in deep water on floodplains and swamps. The depth and timing of filling of these swamps varies between years due to rainfall variability. Successful rearing of young depends on fine-scale spatial linkages as goslings require access to seeds of annual grasses and herbs present in shallow margins of deeper swamps, and family groups move distances up to 15 km per day from nesting to nesting grounds. Post-breeding birds move between swamps to exploit a succession of resources available throughout the dry season. Throughout much of the dry season they are dependent on corms of the aquatic sedge *Eleocharis dulcis*. Foraging for corms can only occur in relatively shallow water; as waters dry and the mud hardens they are no longer available and birds seek alternative food. Life as a Magpie Goose is a "long convoluted series of linkages" (Woinarski *et al.* 2007). Conservation of the species as an abundant wetland species will entail protection of the full suite of options provided by the extensive wetland estate in northern Australia: disruption of these linkages by for example, displacement of annual grasslands and aquatic herblands by monocultures of introduced pasture grasses will sever important links. The conservation challenge is to maintain options in landscapes providing a shifting mosaic of opportunities. The requirement for a succession of resources provided within different vegetation communities is demonstrated by other predominantly granivorous waterfowl species in the Top End, including the Green Pygmy-goose *Nettapus pulchellus* (Dostine, unpublished data).

The Gouldian Finch *Erythura gouldiae* is an endangered granivorous bird formerly abundant throughout large areas of northern Australia, but now restricted to several disjunct and isolated sites. In the Yinberrie Hills area north of Katherine birds undertake an annual shift in habitat from breeding areas in hill woodland and a diet of seed of annual grasses, to non-breeding areas in adjacent lowland grassy woodlands and a diet of seed of perennial grasses (Dostine *et al.* 2001, Dostine and Franklin 2002). The juxtaposition and linkage of these different habitats may be critical for the persistence of this species. Within the wet season birds use seed of a succession of perennial grass species as they become available: consequently, birds depend on heterogeneity of seeding patterns for continuity of food. Uniform fire regimes diminish this heterogeneity and options for finding food during the wet season. Conservation of the Gouldian Finch at this site will entail protection of the full set of habitats and resources used throughout the annual cycle, as well as management actions to promote seeding heterogeneity.

In each example, animals are dependent on specific types of resources or sets of resources available in spatially disjunct habitats. Preservation of these linkages and the capacity of organisms to move between habitats is a *sine qua non* for conservation of these species. Worldwide, there are dramatic examples of the consequences of the disruption of spatial linkages. For example, the collapse of populations of migratory ungulates has been attributed to the disruption of migration routes by habitat loss and barriers to movement (Bolger *et al.* 2008). The population response to migration disruption is often sudden and severe. For example, in the Tarangire ecosystem in northern Tanzania, one of the few remaining sites in Africa where a significant seasonal migration still occurs, populations of three ungulate species (Wildebeest *Connochaetes taurinus*, Hartebeest *Alcelaphus buselaphus* and Oryx *Oryx gazelle*) declined by 88, 90 and 95% between 1988 and 2001 due to habitat loss primarily from agricultural expansion (Bolger *et al.* 2008). Population declines are also evident in populations of migratory neotropical songbirds breeding in North America due at least partly to quality of winter habitats (Sherry and Holmes 1996). Population declines of woodland birds have been observed in the agricultural zones of southern Australia: habitat specialists and those species that move sequentially among several habitats are especially at risk. The loss, or increased isolation, of landscape options that may at times be critical, may be responsible for the decline of floral nomads such as the Regent Honeyeater *Xanthomyza phrygia* and Swift Parrot *Lathamus discolor* (Ford *et al.* 2001). Processes leading to range contraction of species may not threaten extinction of individual species, but constrain numbers such that phenomena involving large numbers of individuals such as spectacular migrations are endangered (Brower and Malcolm 1991). As examples, the phenomena of migrating flocks of Passenger Pigeons *Ectopistes migratorius*, said to darken the skies on their appearance (Gibbs *et al.* 2001); or of huge migratory ungulate herds of Southern Africa, North America and Central Asia (Bolger *et al.* 2008); or the migration of the eastern population of the Monarch Butterfly between breeding and over-wintering sites (Brower 1996), are lost or diminished. Similarly, the phenomenon of large numbers of individuals described by early observers throughout the range of the Flock Bronzewing Pigeon is lost or diminished, presumably as a result of similar processes of loss or degradation of the landscape linkages which sustain large populations.

The Australian continent is characterised by extreme year to year variability in rainfall and primary production (Hobbs *et al.* 1998). Strategies to cope with variation in the abundance of resources include aestivation (van Beurden 1980), fat storage (Morton 1980), diet changes (Franklin and Noske 1999), and movement to locate resources elsewhere in the landscape. Mobility and opportunistic responses to transient resources are common and pervasive characteristics of the Australian avifauna (Gilmore *et al.* 2007, Recher 2007), but evident in a range of other taxa from invertebrates including plague locusts and migratory butterflies (Clark 1971, Dingle *et al.* 2000), small mammals such as dasyurids and rodents in arid regions

(Carstairs 1974, Dickman *et al.* 1995, Haythornthwaite and Dickman 2006), pythons inhabiting seasonally inundated floodplains in northern Australia (Madsen and Shine 1996), macropods (Bailey 1971, Norbury *et al.* 1994), and large introduced herbivores such as feral camels (Grigg 1995).

The field of animal movement is littered with terminological pitfalls (Dean 2003, Roshier and Reid 2003, Gilmore *et al.* 2007), and no attempt will be made here to traverse this field. The definitions used to describe movement are many and imprecise, but largely revolve around the dichotomy between migration and nomadism. The classical notion of migration conjures the seasonal to and fro journeys of temperate zone migrant birds between 'two worlds' of separate fixed breeding and non-breeding habitat. Nomadism departs from the principal features of seasonal migration: there is usually no return journey, breeding and non-breeding habitat are neither fixed nor spatially disjunct, the timing of movements is irregular, and movement pathways are irregular (Roshier and Reid 2003.) These authors distinguish only two types of movement behaviours, maintenance and non-sedentariness, including both migratory and nomadic movements. The term nomadic can imply undirected random searching (Franklin *et al.* 1989): use here is not intended to convey this meaning. I use the general term dispersive in the general sense of Gilmore *et al.* (2007) of undertaking long distance movements.

The complexity of movement patterns within the fauna of northern Australia is aptly described by Woinarski *et al.* (2007), "The movements are regular, chaotic, predictable, indecipherable, solitary, in massed aggregations, local, regional, international." The phenomenon of movement is pervasive and ubiquitous but also subtle and difficult to quantify. Avian movement patterns within Australia tend to be diffuse and cryptic rather than prominent unmistakeable features (Recher 2007), and consequently beyond the consciousness of most Australians.

Early studies using band returns from game-birds (Frith 1959, 1962; Frith and Waterman 1977) provided data on the scale of displacement, but offered few insights on spatial patterns or how movements relate to resource distribution other than in a general sense. For example, Frith and Waterman (1977) monitored a population of Stubble Quail *Coturnix pectoralis* during and following an irruptive invasion, and recorded recoveries more than 1,000 km from the banding site, and Frith (1962) found that Grey Teal *Anas gracilis* demonstrated explosive random dispersal and extensive movement initiated by rain, and proposed that these ecological characteristics might be expected to apply to other birds subjected to similar gross fluctuations of habitat.

Irruptive behaviour is demonstrated by several mainly wetland dependent species as they exploit rare opportunities provided by the flooding of large areas of inland Australia (Robin *et al.* 2009). Waterbirds such as Australian Pelicans *Pelecanus conspicillatus* periodically form large breeding colonies on protected sites within wetland systems in the Lake Eyre Basin (Reid 2009); as resources decline birds undertake a mass exodus to coastal refuges. The Black-tailed Native-hen *Gallinula ventralis* periodically irrupts from drying wetlands of the interior to temporarily occupy marginal habitats in southern Australia (Matheson 1974, 1978) to return soon after inland rainfall. Irruptions of the Letter-winged Kite *Elanus scriptus* have occurred in the wake of the collapse of prey populations in the Channel Country of central and western Queensland (Hollands 1979).

Migration patterns within the eastern Australian bird fauna were inferred from analysis of atlas data (Griffioen and Clarke 2002). Inland patterns of movement were found to be difficult to categorise due to insufficient data: nevertheless six patterns were distinguished, five of which show the northward displacement of the over-wintering range in relation to the breeding range. Eighteen species were categorised as demonstrating confused movement patterns. Large-scale movements were evident in the data for these species but patterns were difficult to perceive. Movement patterns of Flock Bronzewing Pigeons were not categorised. These analyses pool yearly data and consequently may mask idiosyncratic movements in response to aseasonal rainfall events.

Within Australia only the studies of David Roshier and colleagues using satellite telemetry techniques on the nomadic Grey Teal *Anas gracilis* have provided more than glimpses of how mobile organisms interact with resources across large spatial scales (Roshier *et al.* 2006, Roshier, Asmus *et al.* 2008, Roshier, Doerr *et al.* 2008). What is remarkable from these studies is that Grey Teal movements are extensive, rapid and idiosyncratic. There was evidence of directed movements to distant rainfall and flooding, but also exploratory 'ranging' movements conducted in the absence of movement cues. These exploratory movements may develop spatial memory and be advantageous when local conditions deteriorate and birds rely on the knowledge of the spatial distribution of resources at broad scales (Bennetts and Kitchens 2000). The results strongly suggest prior knowledge of environmental conditions at distant sites, though the mechanisms involved remain a perplexing mystery. Suggested mechanisms include visual cues, low frequency sound and/or temperature and pressure gradients associated with passing weather gradients (Simmons *et al.* 1998, Roshier 2009). There is a growing body of evidence that some birds including pigeons and procellariiform seabirds can use olfactory cues for navigation and foraging (Wallraff 2004, Nevitt 2000).

The aforegoing discussion highlights the need for biodiversity conservation strategies to acknowledge the needs of dispersive taxa, and maintain interconnectedness with other landscape elements vital for the survival of species. Mobile species can have large area requirements and conservation areas, even very large areas, can rarely provide for the complete needs of dispersive species. For example, Kakadu National Park in the Northern Territory covers an area of nearly 20,000 km^2 including large areas of coastal wetland and waterbird habitat, but does not provide year-round habitat for the Magpie Goose which depend on a large spatial network of wetland habitats beyond the boundaries of the conservation area (Whitehead *et al.* 1992). The conservation challenge is to maintain as many habitat options as possible by augmenting the protected areas with off-reserve conservation systems.

Dispersive species defy adequate conservation within a fixed system of reserves (Woinarski *et al.* 1992, Recher 2007). Adequate conservation of these species demands knowledge of the ecological requirements of species and recognition of the importance of maintaining interconnectivity of extensive ecological processes (Soule *et al.* 2004). Conventional conservation planning aims to preserve representative samples of mapped vegetation communities as surrogates for biodiversity. Algorithms are available to design reserve networks to select from an array of land units to optimise representation of species or communities (Woinarski *et al.* 1992). The result is frequently scattered and isolated discrete conservation areas surrounded by land uses which may be antipathetic to conservation goals. Protected areas in Australia comprise 6-12% of the area of individual states – estimates of area requirements for adequate biodiversity conservation are invariably higher. For example, Archer (2002) proposed that a minimum of 20% may be required, while Recher (2007) proposed that a minimum of 50% may be required for conservation of biodiversity. Large-scale land acquisition is expensive and politically unacceptable. Consequently, adequate conservation of dispersive species requires sympathetic management of lands outside the conservation estate.

Morton *et al.* (1995) proposed a tiered system of protection of resource-rich patches within the landscape for adequate conservation of biological diversity in arid and semi-arid regions of Australia. The structure of a regional reserve network would include large protected areas which adequately sample regional ecosystem diversity and with a high density of resource-rich patches; significant resource-rich patches excised from production land uses; and areas identified as deserving temporary protection such as waterbird breeding areas or drought refuges. These exist within a broad landscape managed to meet sustainable production goals.

There appears to be high overlap between the habitat requirements of the Flock Bronzewing Pigeon and lands favoured for pastoral production i.e. the relatively fertile black soil plains dominated by the perennial tussock-grass known as Mitchell grass (Higgins and Davies 1996). Mitchell grasslands are under-represented in the national reserve system: only 1.1% of the area of Mitchell grasslands in northern Australia is in conservation reserves, and only 0.5% in the Northern Territory, mostly within the 259 km^2 Connell's Lagoon Conservation Reserve on the Barkly Tableland. The probability of significant expansion of the conservation estate within Mitchell grasslands is low, and may fail to meet requirements of dispersive species unless designed to span extensive slices of the environmental gradient to allow substantial movements (Woinarski *et al.* 1992). The alternative is to identify patches or habitats within Mitchell grasslands which justify excision or temporary protection, and to select an array to match the spatial requirements of particular species. Knowledge of spatial requirements is the key to adequate and effective conservation.

2.6 SYNOPSIS

Columbids are among the most successful avian families: they are cosmopolitan and widespread with over 300 species occupying habitats in every region of the world except Antarctica and the high arctic (Baptista *et al.* 1997). Pigeons generally have powerful flight and a propensity for high mobility. Frugivorous species wander nomadically to exploit patchily distributed fruit resources across large areas (Frith 1982); the genus *Gallicolumba* is an adept colonist of oceanic islands; some species in the genera *Ptilinopus* and *Ducula* have evolved into 'super-tramps' which exploit resources distributed across island groups (Gibbs *et al.* 2001); the Australian Flock Bronzewing Pigeon is regarded as an 'ultra-nomad'. The ecological attributes which underpin the success of columbids may perversely be responsible for the perilous conservation status of many taxa. About a third of all known extant columbid species face some degree of extinction threat: few large bird families contain such a high proportion of threatened species. Insular endemic forms are threatened by habitat loss and alien predators; species with large area requirements are threatened by habitat loss and fragmentation. Twelve species are extinct including the world's fore-most example of bird extinction, the Passenger Pigeon *Ectopistes migratorius* of north America.

In Australia, no mainland species of columbid is extinct, though many species have declined in abundance (Franklin 1999). The Flock Bronzewing Pigeon may have been the most numerous bird in Australia prior to settlement (Lindsey 1995). Populations are now depleted relative to reports in the early ornithological literature; the southern portion of its range was vacated soon after the introduction of grazing stock; the phenomenon of large nesting colonies appears to have vanished. Existing knowledge of the ecology of this species largely stems from the fragmentary records of early explorers and pastoralists; scientific studies are limited to observations on diet (Frith *et al.* 1976). The species is thought to favour tussock grasslands dominated by the perennial grass *Astrebla*, and is assumed to be nomadic throughout semi-arid regions in response to shifting patterns of primary production driven by erratic and variable rainfall. The relatively fertile black-soil plains occupied by these perennial grasslands are favoured by the grazing industry, and are under-represented in the conservation estate. Sustainable use of these grasslands demands that proper consideration be given to the ecological requirements of grassland fauna.

Dispersive taxa which exploit resources across large temporal and spatial scales present considerable challenges to researchers and conservation managers. For the Flock Bronzewing Pigeon this challenge is compounded by the lack of ecological data, and the monopoly of preferred habitats by non-conservation land uses. Conservation solutions for this species and other dispersive taxa in semi-arid pastoral regions will need to collaborative, innovative and under-pinned by sound ecological understanding.

Chapter 3: BROAD-SCALE DISTRIBUTIONAL MODELLING

3.1 INTRODUCTION

Flock Bronzewing Pigeons occur throughout large areas of northern and central Australia, mainly in the arid tropical inland regions (Higgins and Davies 1996). Their stronghold is purported to be the Barkly Tableland in the Northern Territory (Parker 1969, Frith 1982), though this assertion appears to be based on relatively few records. Principal habitats include Mitchell Grass grasslands on black soil plains (Frith 1982, McAllan 1996), chenopod shrublands (Williams 1970), and gibber and sand plains covered with native grasses (Fraser 1990). Vagrant individuals or small groups have been recorded on dry sedge plains in the coastal Northern Territory (Crawford 1972), and even coastal mudflats, occasionally far from large expanses of native tussock grassland. These disparate records suggest that the species can occupy a broad range of open habitats with differing plant communities. However, rigorous analyses of habitat preferences of this species have yet to be undertaken. Likewise there has been no attempt to model the distribution of this species. Distributional modelling is a widely used tool of ecological research which can provide insights into the processes that structure animal populations (Walker 1990, Mackey and Lindenmayer 2001), and identify the potential distribution of declining or invasive species of management concern. Examples from northern Australia include modelling of microchiropteran bat species (Milne *et al.* 2006), the endangered Northern Quoll *Dasyurus hallucatus* (Woinarski *et al.* 2008), and invasive pasture grasses (Ferdinands *et al.* 2005). Olsen and Doran (2002) used distributional modelling to distinguish the core and irruptive ranges of the Grass Owl *Tyto capensis*.

In this chapter I quantify the habitat preferences of the Flock Bronzewing Pigeon by intersecting the coordinates of locality data with digital maps of broad-scale environmental features including continental bioregionalisation, soil type, and land disturbance categories. I summarise the spatial patterns of occurrence within one degree cell units for all records; for recent records (since 1970); and by the frequency of records across years. Further I develop four predictive spatial models based on different data subsets and attributes of fifteen climatic and physical variables. This chapter addresses the following research questions:

(1) What are the broad-scale habitat associations of the Flock Bronzewing Pigeon?

(2) Can statistical modelling be used to identify habitat correlates and predict spatial distribution of this species?

(3) Can evidence from database records define the 'core' range of this species?

(4) What is the evidence for range contraction in this species?

3.2 METHODS

3.2.1 Data collation

Locality records for Flock Bronzewing Pigeons were collated from various sources including datasets from the historic, first and second atlas of Australian birds from Birds Australia; records submitted to Birds Australia subsequent to the second atlas; recent records published in the ornithological literature; records obtained through an appeal for information in the Volunteer newsletter of Birds Australia and from other contacts; the vertebrate fauna atlas maintained by the Northern Territory Department of Natural Resources, Environment, the Arts and Sport (NRETAS); and from unpublished research studies conducted within this organisation. Identical records were present in different data sets; these were identified and duplicates were excluded. Many database records were derived from the historic literature; where possible the original sources were located and checked.

3.2.2 Frequency of records by state and within bioregions

The frequency of Flock Bronzewing Pigeon records by state and within biogeographic regions defined by the Interim Biogeographic Regionalisation for Australia (IBRA) classification scheme (Thackway and Cresswell 1995) was examined using ArcGIS (ESRI 2004). A point file containing the coordinates of locality records was intersected with digital maps of state and IBRA boundaries.

3.2.3 Frequency of records by soil texture classes and disturbance categories

The frequency of Flock Bronzewing Pigeon records by soil texture and disturbance categories was examined using ArcGIS. A point file containing the coordinates of locality records was intersected with digital maps of soil texture (Bureau of Rural Sciences after Commonwealth Scientific and Industrial Research Organisation 1991), and the Vegetation Assets, States and Transitions (VAST) classification of human modification of Australian landscapes (Thackway and Lesslie 2005).

3.2.4 Data display

Locality records for Flock Bronzewing Pigeons were mapped using ArcGIS. Records prior to and from 1970 were overlain on a map of uniform cracking clay soils categorised by VAST landscape disturbance classes. The feature file of soil texture classes was converted to a grid file with 0.01° pixels and same spatial extent as the VAST grid. Uniform cracking soils were assigned a value of 1; other cells were assigned a value of NoData. These grids were multiplied together to provide a composite map of disturbance classes within uniform cracking soils.

3.2.5 Patterns of annual frequency of occurrence

The frequency of annual occurrence within one degree cells (the number of unique years with records) was calculated and displayed using ArcGIS. This potentially identifies core habitat but suffers from unquantified distortion from differences between cells in the frequency of visits by observers. The analysis was conducted for the total data set, and repeated using only recent records from and including the year 1970.

3.2.6 Environmental variables

Twelve continuous and three categorical variables were used in modelling (Table 3.1). Climatic variables were derived from ANUCLIM (Houlder 2000). These included annual mean temperature, maximum temperature, annual temperature range, annual mean rainfall, standard deviation annual rainfall, rainfall seasonality (the standard deviation of weekly mean rainfall). The proportion of summer rainfall (sum of mean monthly rainfall October to March divided by annual mean) was derived from mean monthly rainfall surface data. Elevation and topographic roughness index were derived from a digital elevation model; the topographic index is the range of elevational values in a 3 x 3 cell neighbourhood. Other variables include flatness class, soil texture (Bureau of Rural Sciences after Commonwealth Scientific and Industrial Research Organisation, 1991), and the Vegetation Assets, States and Transitions (VAST) classification of human modification of Australian landscapes (ANU). There are 6 cover classes in VAST representing increasing degrees of modification of native and non-native vegetation cover.

All digital data were converted to a resolution of 0.1 geographic degrees. This approximates to cells of an area of 100 km^2. This resolution is considered appropriate to the scale of input data and the scale of routine movements of the species.

Table 3.1 List of predictor variables used in distributional modelling.

Variables	Excluded from modelling	Model term	Units/values
Annual mean temperature		mean temp	°C
Maximum temperature	x		°C
Temperature range		temp range	°C
Annual rainfall		mean rain	mm
Standard deviation annual rainfall	x		
Rainfall seasonality		rain cv	
Proportion summer rain	x		Proportion of mean annual rainfall in October-March, (0-1)
Elevation		dem	m
Topographic roughness index		topo rough	m
Flatness class		flatclass	
Soil texture		soils	Undefined; uniform coarse; uniform medium; uniform fine; uniform cracking; gradational calcareous; gradational; duplex
Latitude	x		Decimal °S
Longitude		long	Decimal °E
Landscape modification index		VAST	Bare; residual; modified; transformed; replaced; removed

3.2.7 Modelling

Correlated variables (with paired correlation coefficients >0.8) were deleted from the analysis by random selection of one of the pair of correlated variables: latitude, maximum annual temperature, standard deviation of annual rainfall, and the proportion of summer rainfall were thus excluded. Generalised linear modelling (GLM) was used with a binomial error distribution and logit link function to derive minimum adequate models. All modelling was conducted using the R software package (R Development Core Team 2008). The Akaike Information Criterion corrected for small sample size (AIC_c) (Burnham and Anderson 2002) was used as an objective means of model selection. The approach identifies the most parsimonious model from a set of candidate models given maximised log-likelihood of the fitted model. The relative values (AIC_c differences or d.AIC_c) of each model over the set of models being considered were taken as the relative level of empirical support for each model. Values between 0-2 provide substantial support, 4-7 considerably less and >10 essentially none (Burnham and Anderson 2002). Given AIC_c differences for each model, the relative likelihood of a set of candidate models was calculated using Akaike weights (wi). The weight of any particular model depends on the entire set of candidate models, and varies from 0 (no support) to 1 (complete support). The number of model parameters is given by k in tables of modelling results.

Four models were derived using different sub-sets of presence and random 'pseudo-absence' data. The data set does not include sites at which Flock Bronzewing Pigeons were known to be absent, consequently a GIS was used to generate random points ('pseudo-absences'). For all models, locality data were culled for positional accuracy; coastal and near coastal vagrants were removed as were duplicates within the same 0.1 degree cell. Model 1 used 536 presence data points and the same number of pseudo-absence data points derived from the continental extent. Model 2 used 536 presence data points and pseudo-absence points generated from within an envelope containing all the modelled points; model 3 used a sub-set of 460 data points collected since 1970 and pseudo-absence points from within the envelope; model 4 used 298 data points from cells in which Flock Bronzewing Pigeons were recorded in at least 5 different years, and pseudo-absence points from within the envelope. For model 4 the number of categories of soil texture was reduced from 8 to 6. A quadratic term was included for the variable longitude.

The overall modelling strategy was a two stage process involving assessment of the full set of continuous variables and each of the three categorical variables i.e. Soil type, Flatness class and VAST class. Variables in the selected model from this step were then subjected to a step-down approach with serial deletion of non-significant variables. In addition, each of the final models using four datasets were compared to a model with the addition of the variable VAST to assess whether the inclusion of a disturbance-related variable significantly improves any model. An interaction term SOIL*VAST was assessed for all models at this stage, but could only be fitted in model 3.

3.2.8 Caveats and interpretation

There are a number of caveats to be considered in relation to these analyses. Firstly, the use of randomly selected 'pseudo-absence' data must be considered a compromise solution to the problem of lack of known absence data. The modelling assumes the probability of occurrence at 'pseudo-absence' points to be zero, whereas in fact it is unknown. There is a large recent literature on estimating detection functions explicitly in models of probability of occurrence (MacKenzie *et al.* 2006). An alternative solution may have been to limit analyses to data from bird atlas surveys with standardised effort: this would have severely limited the sample size available for analyses. The second issue is the appropriateness of the spatial scale of the modelling. The cell size of 0.1 geographic degrees was selected for modelling as it was considered to be a reasonable match for the expected scale of routine movements of this species, though such details are largely lacking. The third issue is bias in spatial distribution of records. Faunal records are frequently confined to major travelling routes, and the vast areas of sparsely populated lands are highly under-represented. The fourth issue is relevance: detections might not imply occupancy or use of a given area. Many records may potentially derive from observations of dispersing individuals and the environmental attributes at the location of the sighting may have no bearing on the resource requirements of the species.

3.3 RESULTS

3.3.1 Frequency of occurrence by state, bioregion, soil type and disturbance category

The compiled dataset includes 1,232 unique records. Most Flock Bronzewing Pigeon records (79.6%) occurred in either the Northern Territory or Queensland (Table 3.2), and within either the Mitchell Grass Downs or the Channel Country bioregions (Table 3.3, Figure 3.1). Flock Bronzewing Pigeons were recorded from 44 IBRA bioregions but only four bioregions contained greater than 50 individual records. The majority of records (63.5%) occurred within uniform cracking clay soils: the percentage frequency of occurrence in most other soil types was <10% (Table 3.4). A majority of records (82.2%) occurred within either 'modified' or 'transformed' land disturbance classes (Table 3.5). This mirrors the fact that uniform cracking clay soils have been extensively exploited for pastoralism or cropping (Table 3.6).

Table 3.2 The frequency of Flock Bronzewing Pigeon records by state.

State/Territory	Number of records	% no. of records
Northern Territory	548	44.5
Queensland	432	35.1
South Australia	96	7.8
Western Australia	92	7.5
New South Wales	63	5.1
Tasmania	1	0.1
Total	1,232	

Table 3.3 The frequency of Flock Bronzewing Pigeon records by IBRA bioregion.

IBRA bioregion	Number of records	% no. of records
Mitchell Grass Downs	488	39.6
Channel Country	283	23.0
Ord Victoria Plain	74	6.0
Tanami	55	4.5
Other	332	26.9
Total	1,232	

Table 3.4 The frequency of Flock Bronzewing Pigeon records by classification of soil texture.

Soil texture	Number of records	% number of records
Duplex	121	9.8
Gradational	72	5.8
Gradational Calcareous	14	1.1
Undefined	7	0.6
Uniform Coarse	133	10.8
Uniform Cracking	782	63.5
Uniform Fine	61	5.0
Uniform Medium	42	3.4
Grand Total	1,232	

Table 3.5 The frequency of Flock Bronzewing Pigeon records by VAST classification of human modification of Australian landscapes.

VAST class	Number of records	% number of records
0. Bare	14	1.1
1. Residual	169	13.7
2. Modified	431	35.0
3. Transformed	582	47.2
4/5. Replaced	28	2.3
6. Removed	8	0.6
Total	1,232	

Table 3.6 Frequency of 0.01 degree cells of uniform cracking clay soil type within VAST classification of human modification of Australian landscapes.

VAST class	Number of cells	% number of cells
0. Bare	11,215	1.4
1. Residual	63,062	7.9
2. Modified	255,952	32.2
3. Transformed	272,789	34.3
4/5. Replaced	190,954	24.0
6. Removed	1,012	0.1
Total	794,984	

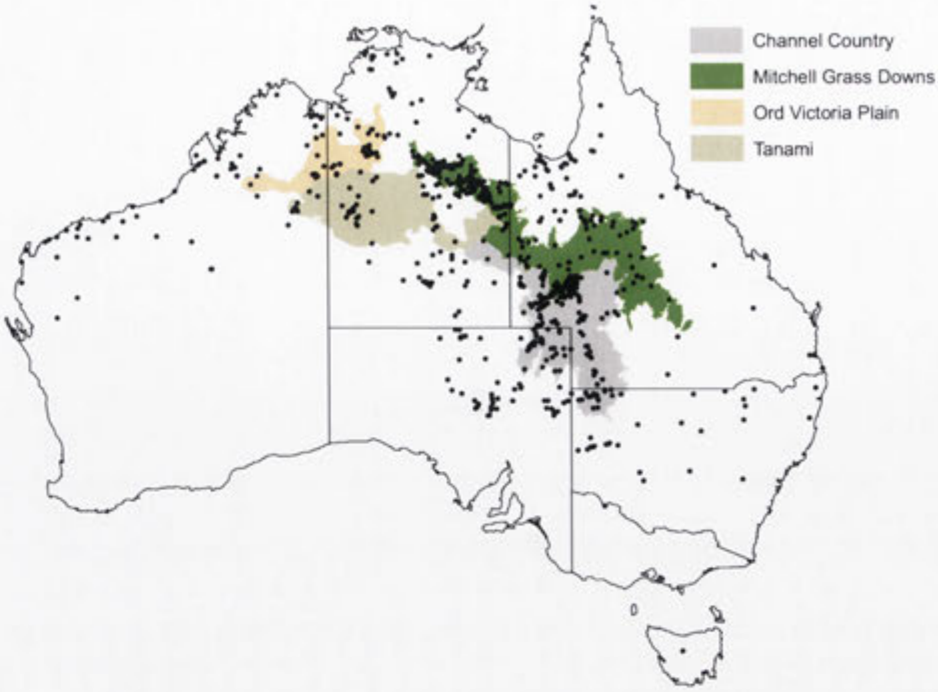


Figure 3.1 Distribution of Flock Bronzewing Pigeon records overlain on four IBRA bioregions.

3.3.2 *Distribution of records prior to, and from, the year 1970*

The distribution of Flock Bronzewing Pigeon records prior to 1970 is mapped in Figure 3.2. Records are relatively sparse (n = 167, 13.6% of total number of records), but span the northern half of the continent with the exception of the inland areas of northern Western Australia and the south-western portion of the Northern Territory. The distribution of records of Flock Bronzewing Pigeons from 1970 is mapped in Figure 3.3. These records comprise 84.1% of the total number of records and similarly occur throughout large areas of the northern portion of the continent with the exception of the far western periphery and the eastern portion of the original range. With the exception of a handful of coastal records of presumably vagrant birds, they have vacated large areas of alienated habitat in northern New South Wales and southern Queensland.

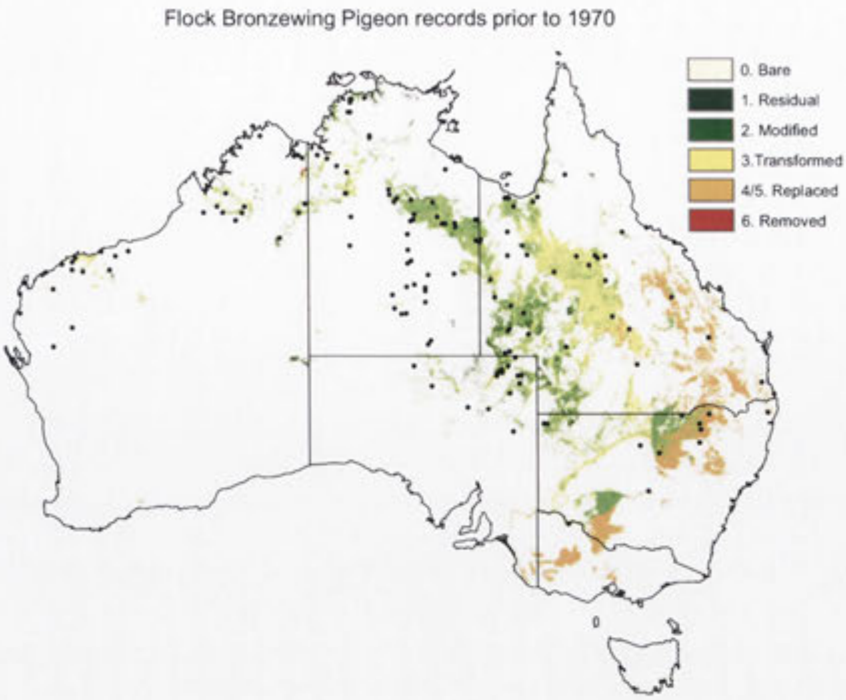


Figure 3.2 Distribution of Flock Bronzewing Pigeon records prior to 1970.

Records overlain on distribution of uniform cracking soils categorised by VAST classes of human modification of vegetation (Thackway and Lesslie 2005), n=167.

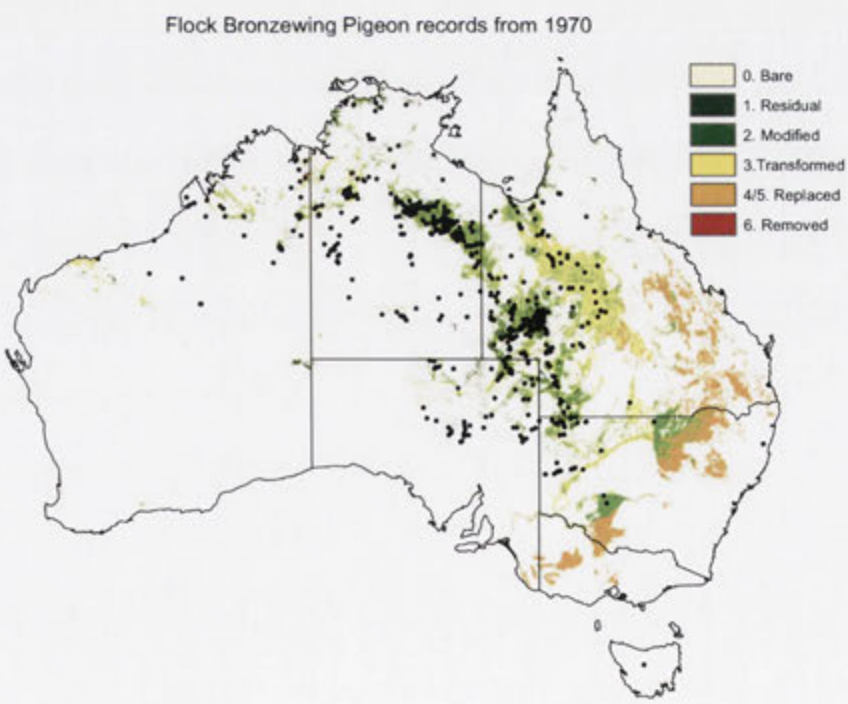


Figure 3.3 Distribution of Flock Bronzewing Pigeon records from 1970.

Records overlain overlain on uniform cracking soils categorised by VAST classes of human modification of vegetation (Thackway and Lesslie 2005), n= 1,036.

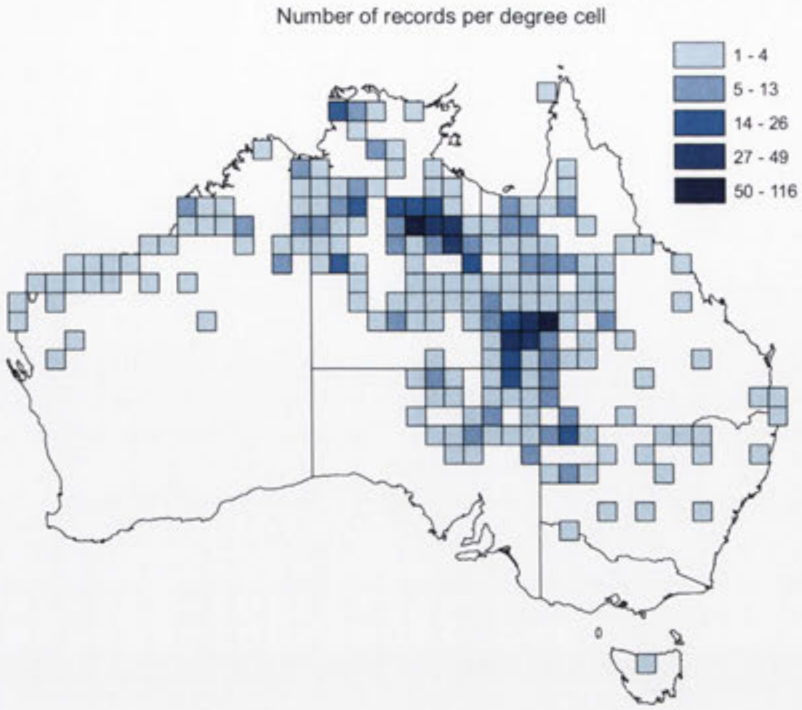


Figure 3.4 Map showing the total number of records per degree cell.

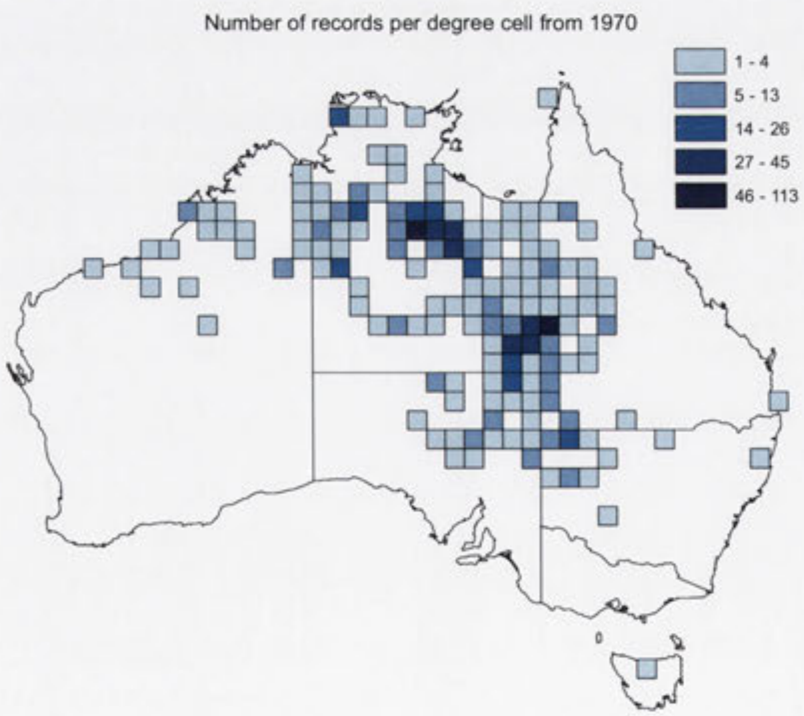


Figure 3.5 Map showing the number of records per degree cell from 1970.

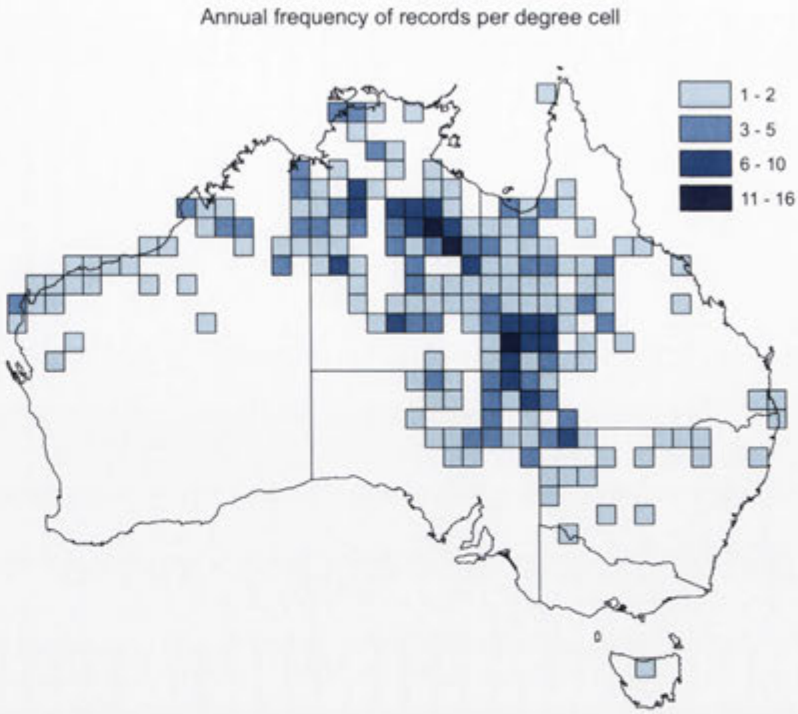


Figure 3.6 Map showing the frequency of annual occurrence per degree cell from all date-referenced records.

3.3.3 Number of records by degree cell

The total number of records by degree cell (Figure 3.4) and the number of records from 1970 (Figure 3.5) both highlight the high frequency of records within the Barkly region of the Northern Territory and the Channel Country region of far south-west Queensland. There are Flock Bronzewing Pigeon records within 203 of the approximately 693 one degree cells covering the Australian continent, or approximately 30% of the number of degree cells. Flock Bronzewing Pigeons were recorded from 153 one degree cells from 1970, a range decline of approximately 25%.

3.3.4 Patterns of annual frequency of occurrence

The frequency of annual reports varied across the species range (Figure 3.6). Of 195 cells with dated Flock Bronzewing Pigeon records 90 (46%) are represented by a single year (Figure 3.7). Although individuals can occur throughout much of the northern part of the continent in most areas these are rare ephemeral events. Absences from the recorded range are mostly from the south-eastern and western portion of the original range. The strongholds of the species appear to be the Barkly Tableland in the Northern Territory and the Channel Country in far south-west Queensland.

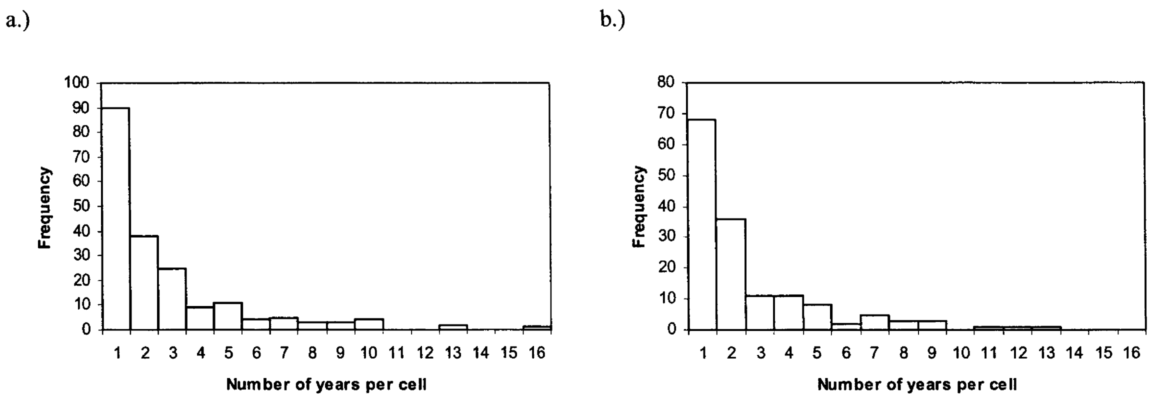


Figure 3.7 Frequency histograms of number of years per cell.

a.) total record for all years, b.) record for years since 1970.

There are 11 distinct groups of single or clustered cells with records from five or more years (Figure 3.8). Two of these clusters might be regarded as the core habitat of the species: one cluster comprising ten degree cells overlying the Northern Territory portion of the Mitchell Grass Downs, and a second cluster comprising ten degree cells in the Channel Country region of south-west Queensland and north-east South Australia. In contrast, the central portion of the Mitchell Grass Downs region in Queensland is vacant.

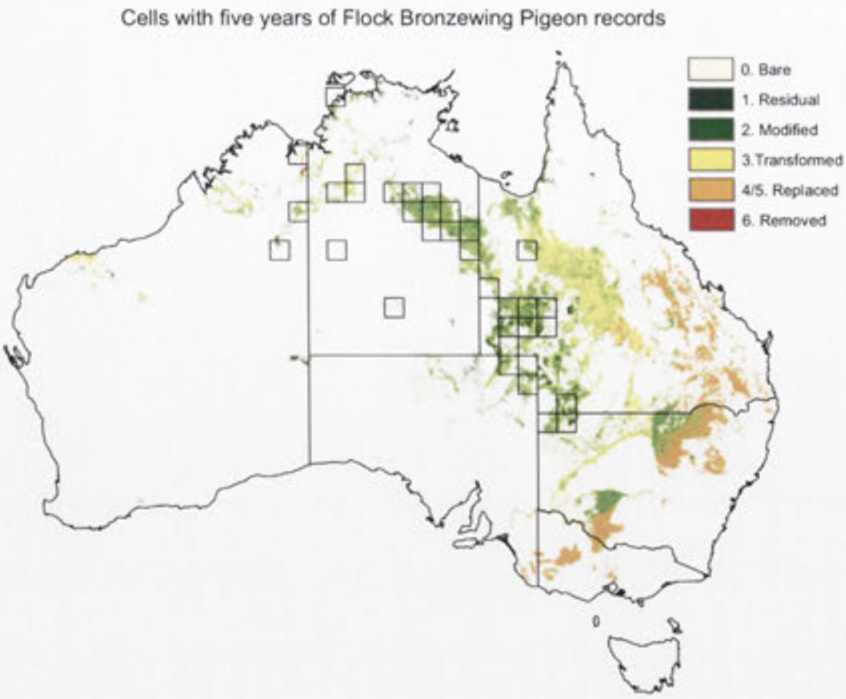


Figure 3.8 Map showing distribution of degree cells with records from at least five years.

Degree cells are overlain on distribution of uniform cracking soils categorised by VAST classes of human modification of vegetation (Thackway and Lesslie 2005).

3.3.5 Modelling

Generalised linear modelling generated predictive models which differed in the amount of explained model deviance depending on the constraints on the data. The model variables differed subtly between models but included soil texture, mean annual rainfall, mean annual temperature, temperature range, rainfall seasonality, elevation and longitude. Analysis of model 1 data yielded a model which explained 54.6% of the model deviance and included the variables soil texture, mean annual rainfall, mean annual temperature, rainfall seasonality, elevation, longitude and quadratic function of longitude (Tables 3.7-3.9). Analysis of model data 2 yielded a model which explained 26.8% of the model deviance and included the variables soil texture, mean annual rainfall, mean annual temperature, longitude, quadratic function of longitude and temperature range (Tables 3.10-3.12). Analysis of model data 3 yielded a model which explained 28.3% of the model deviance and included the variables soil texture, mean annual rainfall, rainfall seasonality, elevation, longitude and quadratic function of longitude (Tables 3.13-3.15). Analysis of model data 4 yielded a model which explained 49.8% of the model deviance and included the variables soil texture, mean annual rainfall, rainfall seasonality, elevation, longitude and quadratic function of longitude (Tables 3.16-3.18). Two models (model 1 and model 4, were robust, i.e. model deviance >30%); all models yielded similar spatial predictions (Figures 3.9-3.12). The spatial predictions of models based on all data (model 2), or only data since 1970 (model 3), were similar and there is little evidence from modelling of a marked reduction in range.

3.3.6 Effect of addition of disturbance variable VAST

The inclusion of the landscape modification variable (VAST) led to only minor increases in explained deviance (Tables 3.19-3.26). Increases in explained deviance ranged from only 1.0 to 3.7%, and averaged 1.9%. The spatial predictions of model 4 largely coincide with core cells (i.e. degree cells with at least 5 annual records) with the exception of the large area of predicted suitable habitat in central Queensland. This area is dominated by the Transformed class of the VAST classification. In this class native vegetation community structure and composition has been significantly altered by land management practice, in this case heavy grazing of native grasslands principally by sheep.

Table 3.7 Results of generalised linear modelling of all continuous variables and three categorical variables (Soils, Flatclass and VAST) using model 1 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-334.40	15	699.25	0.00	1.000	54.7
Flatclass + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-357.90	13	742.14	42.89	0.000	51.5
VAST + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-360.29	15	751.03	51.78	0.000	51.1
mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-384.98	10	790.17	90.92	0.000	47.8
Soils	-519.10	7	1052.31	353.06	0.000	29.6
Flatclass	-588.76	5	1187.58	488.33	0.000	20.2
VAST	-638.29	7	1290.69	591.44	0.000	13.5
Null model	-737.51	2	1479.02	779.77	0.000	0.0

Table 3.8 Results of generalised linear modelling of categorical variable Soils and all continuous variables by serial deletion of least significant variable using model 1 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + mean rain + mean temp + rain cv + dem + long + long^2	-334.94	13	696.22	0.00	0.500	54.6
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2	-334.45	14	697.31	1.09	0.288	54.7
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-334.40	15	699.25	3.03	0.109	54.7
Soils + mean rain + mean temp + dem + long + long^2	-337.50	12	699.30	3.07	0.107	54.2
Soils + mean temp + dem + long + long^2	-346.61	11	715.46	19.24	0.000	53.0
Soils + mean temp + long + long^2	-359.47	10	739.15	42.93	0.000	51.3
Soils + mean temp + long	-396.63	9	811.43	115.20	0.000	46.2
Null model	-737.51	2	1479.02	782.80	0.000	0.0

Table 3.9 Parameter estimates of preferred model using model 1 data.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-241.300	30.470	-7.92	0.0000	***
Mean rain	-0.003	0.001	-4.18	0.0000	***
Mean temp	0.285	0.099	2.89	0.0039	**
Rainfall cv	0.017	0.008	2.28	0.0225	*
Elevation	-0.004	0.001	-5.75	0.0000	***
Longitude	3.430	0.461	7.43	0.0000	***
Longitude^2	-0.013	0.002	-7.29	0.0000	***
Soil texture (uniform medium)	-0.256	0.361	-0.71	0.4772	ns
Soil texture (uniform cracking)	2.833	0.331	8.55	0.0000	***
Soil texture (gradational calcareous)	-0.135	0.462	-0.29	0.7701	ns
Soil texture (gradational)	1.090	0.329	3.31	0.0009	***
Soil texture (duplex)	1.378	0.311	4.42	0.0000	***
Soil texture (uniform coarse)	aliased				

Table 3.10 Results of generalised linear modelling of all continuous variables and three categorical variables (Soils, Flatclass and VAST) using model 2 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-522.47	15	1075.40	0.00	1.000	27.0
VAST + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-537.33	15	1105.14	29.73	0.000	24.9
Soils	-587.71	7	1189.52	114.12	0.000	17.9
Mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-597.30	10	1214.81	139.40	0.000	16.6
Flatclass + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-594.73	13	1215.82	140.41	0.000	16.9
VAST	-653.06	7	1320.22	244.82	0.000	8.8
Flatclass	-686.84	5	1383.74	308.33	0.000	4.1
Null model	-715.96	2	1435.94	360.53	0.000	0.0

Table 3.11 Results of generalised linear modelling of categorical variable Soils and all continuous variables by serial deletion of least significant variables using model 2 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + mean rain + mean temp + dem + long + long^2 + temp range	-522.50	13	1071.36	0.00	0.521	27.0
Soils + mean rain + mean temp + long + long^2 + temp range	-524.40	12	1073.11	1.75	0.217	26.8
Soils + mean rain + mean temp + rain cv + dem + long + long^2 + temp range	-522.47	14	1073.35	1.99	0.193	27.0
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-522.47	15	1075.40	4.05	0.069	27.0
Soils + mean rain + mean temp + long + long^2	-531.72	11	1085.70	14.34	0.000	25.7
Soils + mean rain + long + long^2	-540.12	10	1100.45	29.09	0.000	24.6
Soils + long + long^2	-550.90	9	1119.98	48.63	0.000	23.1
Null model	-715.96	2	1435.94	364.58	0.000	0.0

Table 3.12 Parameter estimates of preferred model using model 2 data.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-201.900	27.030	-7.47	0.0000	***
Mean rain	-0.004	0.001	-5.31	0.0000	***
Mean temp	0.259	0.061	4.26	0.0000	***
Longitude	2.968	0.415	7.15	0.0000	***
Longitude^2	-0.011	0.002	-7.05	0.0000	***
Temp range	-0.215	0.057	-3.81	0.0001	***
Soil texture (uniform medium)	0.392	0.351	1.12	0.2644	ns
Soil texture (uniform cracking)	2.432	0.226	10.77	0.0000	***
Soil texture (gradational calcareous)	0.656	0.444	1.48	0.1396	ns
Soil texture (gradational)	0.580	0.267	2.17	0.0298	*
Soil texture (duplex)	1.704	0.260	6.55	0.0000	***
Soil texture (uniform coarse)	aliased				

Table 3.13 Results of generalised linear modelling of all continuous variables and three categorical variables (Soils, Flatclass and VAST) using model 3 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-449.10	15	928.73	0.00	1.000	28.4
VAST + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-466.95	15	964.43	35.70	0.000	25.6
Mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-502.86	10	1025.97	97.24	0.000	19.8
Flatclass + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-500.91	13	1028.23	99.49	0.000	20.1
Soils	-521.45	7	1057.03	128.29	0.000	16.9
VAST	-568.54	7	1151.20	222.47	0.000	9.4
Flatclass	-606.82	5	1223.71	294.98	0.000	3.3
Null model	-627.30	2	1258.61	329.87	0.000	0.0

Table 3.14 Results of generalised linear modelling of categorical variable Soils and all continuous variables by serial deletion of least significant variables using model 3 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + mean rain + rain cv + dem + long + long^2	-449.47	12	923.30	0.00	0.606	28.3
Soils + mean rain + topo rough + rain cv + dem + long + long^2	-449.31	13	925.02	1.72	0.256	28.4
Soils + mean rain + topo rough + rain cv + dem + long + long^2 + temp range	-449.25	14	926.98	3.68	0.096	28.4
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-449.10	15	928.73	5.43	0.040	28.4
Soils + mean rain + dem + long + long^2	-456.62	11	935.53	12.23	0.001	27.2
Soils + mean rain + long + long^2	-465.92	10	952.08	28.78	0.000	25.7
Soils + long + long^2	-475.90	9	970.00	46.70	0.000	24.1
Null model	-627.30	2	1258.61	335.31	0.000	0.0

Table 3.15 Parameter estimates of preferred model using model 3 data.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-274.100	35.190	-7.79	0.0000	***
Mean rain	-0.003	0.001	-5.98	0.0000	***
Rain cv	0.017	0.005	3.73	0.0002	***
Elevation	-0.003	0.001	-4.38	0.0000	***
Longitude	4.113	0.531	7.75	0.0000	***
Longitude^2	-0.015	0.002	-7.73	0.0000	***
Soil texture (uniform medium)	0.768	0.395	1.94	0.0520	ns
Soil texture (uniform cracking)	2.290	0.243	9.45	0.0000	***
Soil texture (gradational calcareous)	0.767	0.523	1.47	0.1430	ns
Soil texture (gradational)	0.356	0.293	1.21	0.2250	ns
Soil texture (duplex)	1.442	0.286	5.05	0.0000	***
Soil texture (uniform coarse)	aliased				

Table 3.16 Results of generalised linear modelling of all continuous variables and three categorical variables (Soils, Flatclass and VAST) using model 4 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-198.94	14	426.63	0.00	1.000	49. 9
VAST + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-227.44	14	483.63	57.00	0.000	42.7
Mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-259.16	10	538.72	112.09	0.000	34.7
Flatclass + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-256.59	13	539.82	113.19	0.000	35.4
Soils	-267.88	6	547.90	121.27	0.000	32.5
VAST	-357.91	6	727.97	301.34	0.000	9.8
Flatclass	-369.05	5	748.21	321.58	0.000	7.0
Null model	-396.98	2	797.98	371.35	0.000	0.0

Table 3.17 Results of generalised linear modelling of categorical variables Soils and all continuous variables by serial deletion of least significant variable using model 4 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils+ mean rain+ rain cv + dem + long + long^2	-199.40	11	421.26	0.00	0.55	49.8
Soils + mean rain + topo rough + rain cv + dem + long + long^2	-198.98	12	422.52	1.26	0.30	49.9
Soils + mean rain + topo rough + rain cv + dem + long + long^2 + temp range	-198.95	13	424.55	3.29	0.11	49.88
Soils + mean rain + mean temp + topo rough + rain cv + dem + long + long^2 + temp range	-198.94	14	426.63	5.37	0.04	49.9
Soils + mean rain + dem + long + long^2	-205.13	10	430.65	9.39	0.01	48.3
Soils + dem + long + long^2	-220.92	9	460.15	38.89	0.00	44.4
Soils + long + long^2	-224.12	8	464.49	43.23	0.00	43.5
Null model	-396.98	2	797.98	376.71	0.00	0.0

Table 3.18 Parameter estimates of preferred model using model 4 data.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-482.300	82.950	-5.81	0.0000	***
Mean rain	-0.006	0.001	-5.21	0.0000	***
Rain cv	0.026	0.008	3.22	0.0013	**
Elevation	-0.005	0.001	-3.62	0.0003	***
Longitude	7.238	1.237	5.85	0.0000	***
Longitude^2	-0.027	0.005	-5.90	0.0000	***
Soil texture (uniform medium)	-0.005	0.710	-0.01	0.9946	ns
Soil texture (uniform cracking)	3.327	0.382	8.72	0.0000	***
Soil texture (gradational)	1.236	0.467	2.65	0.0081	**
Soil texture (duplex)	0.530	0.478	1.11	0.2678	ns
Soil texture (uniform coarse)	aliased				

Table 3.19 Results of adding variable VAST to preferred model using model 1 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + VAST + mean rain + mean temp + rain cv + dem + long + long^2	-338.87	13	704.09	0.00	1.000	54.0
Soils + mean rain + mean temp + rain cv + dem + long + long^2	-350.90	9	719.97	15.87	0.000	52.4
VAST + mean rain + mean temp + rain cv + dem + long + long^2	-364.91	12	754.11	50.02	0.000	50.5
Null model	-736.81	2	1477.63	773.54	0.000	0.0

Table 3.20 Parameter estimates of preferred model using model 1 data with inclusion of variable VAST.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-240.500	31.360	-7.67	0.0000	***
Soil texture (uniform cracking)	1.910	0.288	6.63	0.0000	***
VAST (residual)	-0.200	0.697	-0.29	0.7743	ns
VAST (modified)	0.849	0.706	1.20	0.2292	ns
VAST (transformed)	0.798	0.715	1.12	0.2643	ns
VAST (replaced)	1.258	0.938	1.34	0.1796	ns
Mean rain	-0.003	0.001	-3.94	0.0001	***
Mean temp	0.386	0.104	3.69	0.0002	***
Rain cv	0.012	0.007	1.59	0.1113	ns
Elevation	-0.004	0.001	-5.87	0.0000	***
Longitude	3.354	0.467	7.19	0.0000	***
Longitude^2	-0.012	0.002	-7.03	0.0000	***

Table 3.21 Results of adding variable VAST to preferred model using model 2 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + VAST + mean rain + mean temp + rain cv + dem + long + long^2	-519.02	13	1064.40	0.00	1.000	27.4
Soils + mean rain + mean temp + rain cv + dem + long + long^2	-545.26	9	1108.70	44.30	0.000	23.8
VAST + mean rain + mean temp + rain cv + dem + long + long^2	-543.88	12	1112.08	47.68	0.000	24.0
Null model	-715.28	2	1434.57	370.17	0.000	0.0

Table 3.22 Parameter estimates of preferred model using model 2 data with inclusion of variable VAST.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-219.400	28.770	-7.63	0.0000	***
Soil texture (uniform cracking)	1.354	0.195	6.95	0.0000	***
VAST (residual)	-1.464	0.748	-1.96	0.0505	ns
VAST (modified)	-0.371	0.751	-0.49	0.6210	ns
VAST (transformed)	-0.039	0.756	-0.05	0.9591	ns
VAST (replaced)	0.519	0.970	0.54	0.5927	ns
Mean rain	-0.003	0.001	-4.27	0.0000	***
Mean temp	0.109	0.103	1.06	0.2893	ns
Rain cv	0.011	0.007	1.62	0.1060	ns
Elevation	-0.003	0.001	-4.61	0.0000	***
Longitude	3.256	0.438	7.44	0.0000	***
Longitude^2	-0.012	0.002	-7.38	0.0000	***

Table 3.23 Results of adding variable VAST to preferred model using model 3 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils*VAST + mean rain + mean temp + rain cv + dem + long + long^2	-436.04	13	898.50	0.00	0.980	28.0
Soils + VAST + mean rain + mean temp + rain cv + dem + long + long^2	-441.98	11	906.27	7.76	0.020	27.0
Soils + mean rain + mean temp + rain cv + dem + long + long^2	-453.21	9	924.63	26.13	0.000	25.2
VAST + mean rain + mean temp + rain cv + dem + long + long^2	-463.45	10	947.16	48.66	0.000	23.5
Null model	-605.77	2	1215.56	317.06	0.000	0.0

Table 3.24 Parameter estimates of preferred model using model 3 data with inclusion of variable VAST.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-262.800	36.620	-7.18	0.0000	***
Soil texture (uniform cracking)	2.189	0.484	4.52	0.0000	***
VAST (modified)	0.906	0.243	3.72	0.0002	***
VAST (transformed)	1.573	0.305	5.16	0.0000	***
Mean rain	-0.003	0.001	-4.20	0.0000	***
Mean temp	0.099	0.118	0.84	0.4019	ns
Rain cv	0.015	0.008	1.90	0.0569	ns
Elevation	-0.003	0.001	-4.08	0.0000	***
Longitude	3.872	0.556	6.97	0.0000	***
Longitude^2	-0.014	0.002	-6.92	0.0000	***
Soil 4 : VAST 2	-0.538	0.549	-0.98	0.3273	ns
Soil 4 : VAST 3	-1.739	0.582	-2.99	0.0028	**

Table 3.25 Results of adding variable VAST to preferred model using model 4 data.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Soils + VAST + mean rain + mean temp + rain cv + dem + long + long^2	-197.51	13	421.67	0.00	0.806	50.2
Soils + mean rain +mean temp + rain cv + dem + long + long^2	-203.10	9	424.52	2.85	0.194	48.8
VAST + mean rain + mean temp + rain cv + dem + long + long^2	-228.99	12	482.54	60.87	0.000	42.3
Null model	-396.98	2	797.98	376.30	0.000	0.0

Table 3.26 Parameter estimates of preferred model using model 4 data with inclusion of variable VAST.

Model variable	Estimate	Std error	z value	Pr(>|z|)	Sig.
Constant	-492.500	84.440	-5.83	0.0000	***
Soil texture (uniform cracking)	2.491	0.330	7.54	0.0000	***
VAST (residual)	-0.331	0.935	-0.35	0.7233	ns
VAST (modified)	0.518	0.937	0.55	0.5801	ns
VAST (transformed)	0.653	0.954	0.68	0.4939	ns
VAST (replaced)	3.404	1.879	1.81	0.0700	ns
Mean rain	-0.006	0.002	-4.08	0.0000	***
Mean temp	0.007	0.204	0.04	0.9714	ns
Rain cv	0.029	0.014	2.18	0.0290	*
Elevation	-0.005	0.001	-3.37	0.0007	***
Longitude	7.379	1.271	5.81	0.0000	***
Longitude^2	-0.028	0.005	-5.83	0.0000	***

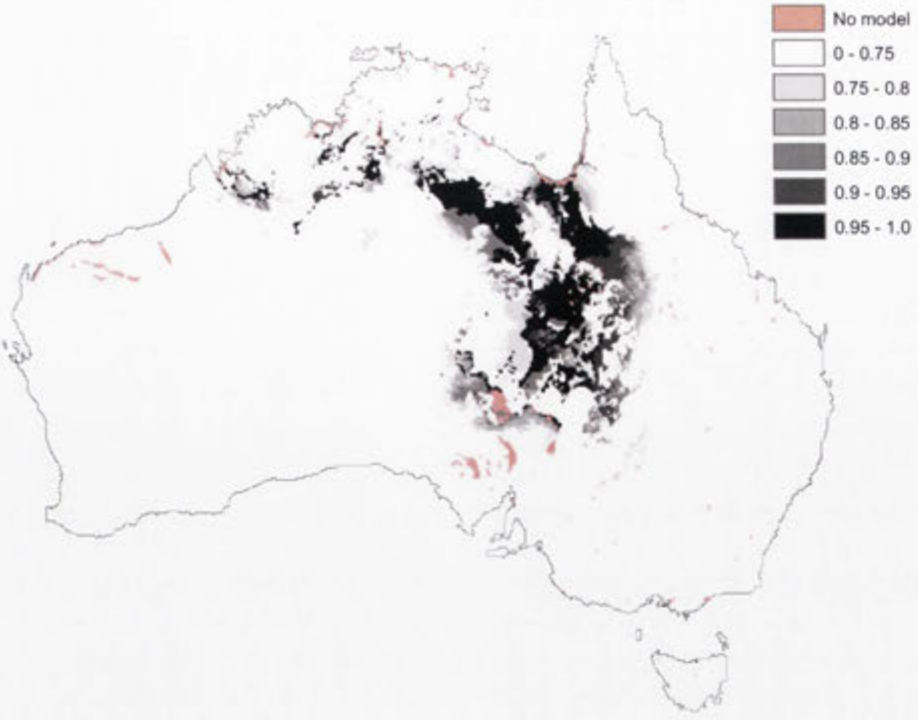


Figure 3.9 Spatial predictions of probability of occurrence (0-1), model 1.

Modelling used 536 presence data points, and 536 pseudo-absence points derived from random selection within continental context.

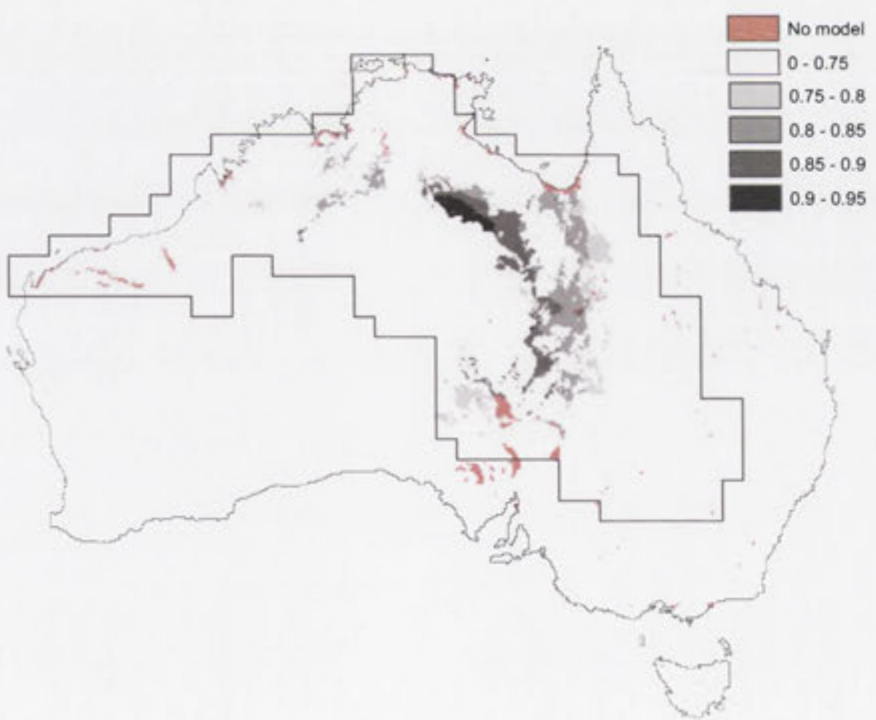


Figure 3.10 Spatial predictions of probability of occurrence (0-1), model 2.

Modelling used 536 presence data points, and 536 pseudo-absence points derived from random selection within defined envelope.

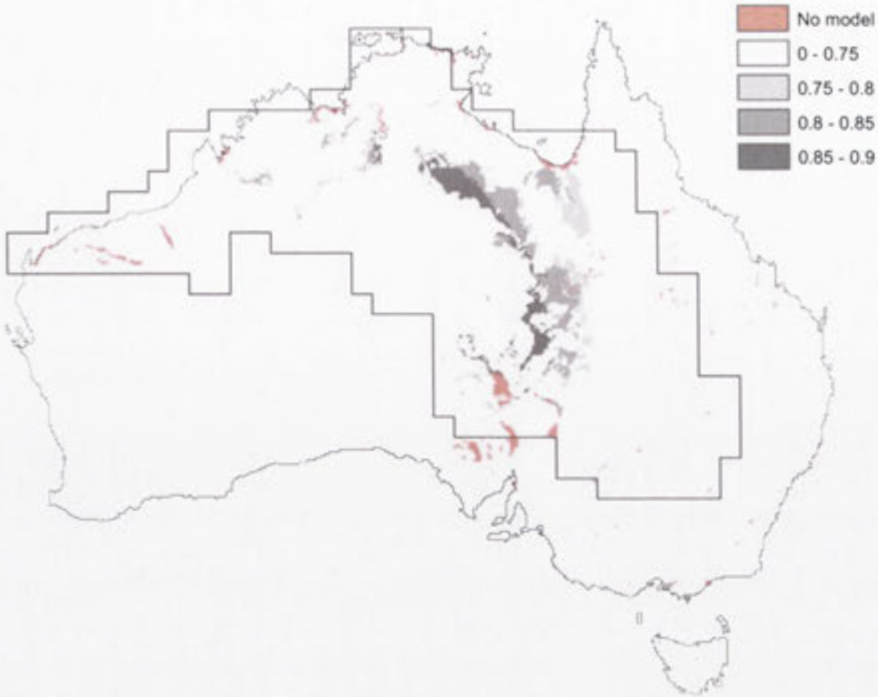


Figure 3.11 Spatial predictions of probability of occurrence (0-1), model 3.

Modelling used 460 presence data points since 1970, and 460 pseudo-absence points derived from random selection within defined envelope.

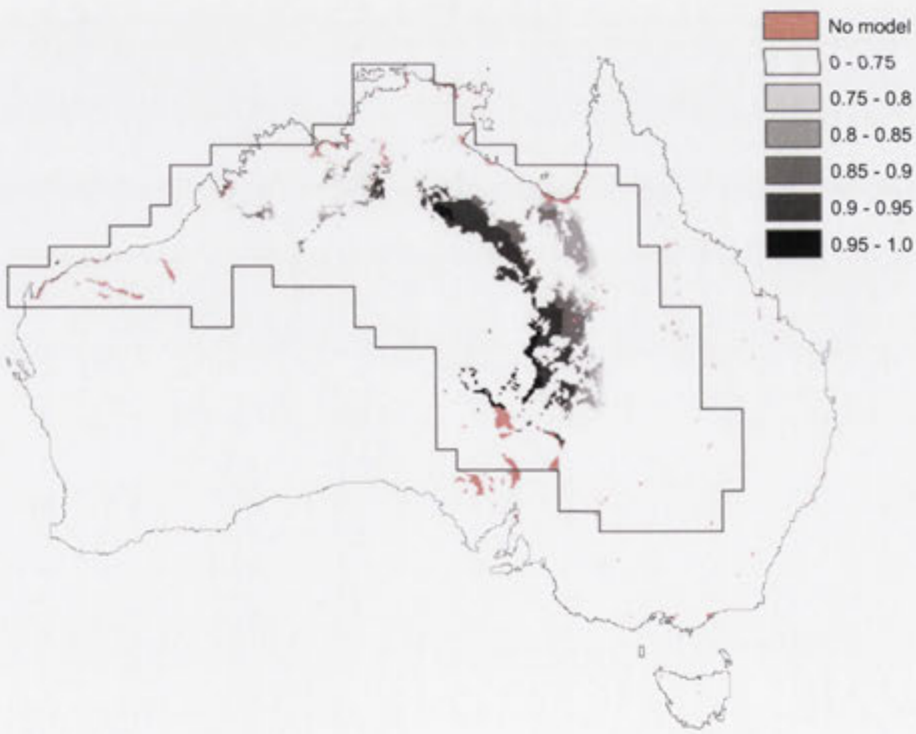


Figure 3.12 Spatial predictions of probability of occurrence (0-1), model 4.

Modelling used 298 presence data points from core cells, and 298 pseudo-absence points derived from random selection within defined envelope.

3.4 DISCUSSION

These results summarise the broad qualitative environmental requirements of the Flock Bronzewing Pigeon and are largely consistent with previous statements on the habitat associations of the species (reviewed in Higgins and Davies 1996). Since 1970 there has been a contraction in occupied range but a vast increase in the number of individual records. This is slightly anomalous but may be a consequence of increased survey effort due to national bird atlas schemes, or a consequence of favourable wetter periods at intervals throughout the period from 1970. What is clear, despite the paucity of historic records, is a withdrawal from the western and eastern periphery of the formerly occupied range. In the east this is associated with alienation of suitable black-soil plain habitat by agricultural development. The region of the encounter with Flock Bronzewing Pigeons by the naturalist John Gould in the Namoi valley is now substantially modified for agriculture (Arthington 1996). The initial threatening process was probably rapid changes in pasture composition by invasion by stock, particularly sheep (Lunney 2001); subsequently these lands have been modified by wheat cultivation and irrigated agriculture. Pastoral development triggered rapid and extreme faunal collapses in eastern Australia (Recher and Lim 1990). Lunney (2001) attributed mammal extinctions in western New South Wales to irreversible loss of primary productivity by sheep grazing. Early reports (summarised in Chapter 2) indicate that Flock Bronzewing Pigeons were frequent and abundant visitors to the plains throughout large areas of New South Wales. The extent to which these areas constituted part of the normal range has been raised previously (McAllan 1996), but the evidence suggests that they were formerly regular and not infrequent visitors (McAllan 1996). Numbers were severely diminished within decades of the initial observations.

Several analyses highlight the importance of both the Barkly Tableland of the Northern Territory and the Channel Country region of far south-west Queensland. For example, Figure 3.8 suggests that both these areas constitute significant habitat and that there are several additional outliers of frequently used habitat. This conflicts with the assertion of Parker (1969) and Frith (1982) that the Barkly region constituted the source of irruptive invasions which dispersed widely to form ephemeral 'sink' populations beyond the region in the wake of favourable seasons. This result immediately raises questions about the nature of exchanges between these 'core areas', between these areas and other outliers, and between core areas and other apparently suitable but less frequently occupied habitat. These questions are partially addressed in Chapter 6.

Spatial modelling revealed a set of common predictor variables including soil type, mean annual rainfall and rainfall seasonality. Soil types with a soil texture described as 'uniform cracking' was consistently identified as a predictive variable. This is consistent with previous descriptions of major habitat associations of the species (Higgins and Davies 1996). Cracking clay soils frequency occur as extensive undulating 'downs' or alluvial plains and support characteristic perennial tussock-grass vegetation. Throughout much of their range within rainfall isohyets of 250-550 mm, uniform cracking clay soils support grasslands dominated by Mitchell Grass *Astrebla* spp.

The four models provided broadly similar predictions of the spatial distribution of the species. Models 2, 3 and 4 were virtually identical despite difference in the spatial and temporal extent of the locality data. These models differed from model 1 in the spatial extent of the predicted distribution. This is largely an artefact of the spatial extent of the pseudo-absence data, which was unconfined in model 1 but confined to a kernel in models 2, 3 and 4. Spatial predictions based on all records versus those from records only from 1970 are near identical. This failure to capture the pattern of range contraction may be due to the low number of records retained in the dataset after culling for geographic precision. Nearly all historic records were geographically imprecise and consequently deleted from modelling. Which of the four models provides the most accurate representation of the distribution of the species is tested in Chapter 5 using an independent data set drawn from a mail-out survey of pastoral landholders.

3.5 SUMMARY OF FINDINGS AND CONCLUSIONS

A dataset of 1,232 unique records of Flock Bronzewing Pigeons was compiled from various sources to summarise distribution patterns and conduct predictive modelling. Records are widely distributed throughout northern and central Australia. The majority of all records (79.6%) occurred in either the Northern Territory or Queensland; 62.6 % of all records occurred within either the Mitchell Grass Downs bioregion (39.6%) or the Channel Country bioregion (23.0%); and 63.5% of all records occurred on uniform cracking clay soils; 82.2% of all records occurred within moderate vegetation disturbance categories.

Generalised linear modelling was used to predict the spatial distribution of Flock Bronzewing Pigeons using 15 climatic, physical and biophysical variables. Four models were derived using different sets of locality data and random 'pseudo-absence' data. Model 1 was based on attributes of records within 0.1° cells and random pseudo-absence data selected from the entire continent; model 2 was based on attributes of the same set of presence data and pseudo-absence points from a kernel enclosing the presence data; model 3 used presence data collected since 1970 and pseudo-absence points from the kernel of model 2; model 4 used presence data from within degree cells with a minimum of 5 years of records and pseudo-absence data from the kernel of model 2. Models explained between 26.8-54.6% of the model deviance. The selected variables differed subtly between models but included soil texture, mean annual rainfall, mean annual temperature, temperature range, rainfall seasonality, elevation and longitude. The inclusion of a land disturbance variable (VAST) in each of the four models led to minor increases in explained deviance. Modelling results are consistent with previous descriptions of the typical habitat of Flock Bronzewing Pigeons i.e. vast open grasslands on fine-textured cracking-clay soils in northern Australia.

Of 195 cells of one degree latitude and longitude with dated Flock Bronzewing Pigeon records 90 (46%) have records within only a single year. Relatively few cells have records for 5 or more separate years; clusters of these cells are centred on the Channel Country in far south-west Queensland, and the Barkly Tableland, Victoria River region and Tanami regions of the Northern Territory. On this basis the core range of the Flock Bronzewing Pigeon occurs within a narrow arc from the Victoria River District in the western Northern Territory, through the Barkly Tableland, south-west Queensland and the north-west corner of New South Wales.

Landscapes with uniform cracking clay soils are extensively utilised for agriculture and pastoral production, especially in the better-watered eastern portion of the continent, and native fauna dependent on native grasslands on these soils have been disadvantaged. In temperate eastern Australia Flock Bronzewing Pigeons vacated these landscapes within decades of pastoral development, most probably due to degradation of vegetation resourced through excessive grazing by sheep. They have also contracted from the western periphery of their original range. However, the appearance of large numbers of Flock Bronzewing Pigeons on the Pilbara coast in Western Australia early last century coincided with an extensive and severe drought in eastern Australia, and above average rainfall (see Chapter 4).

Chapter 4: SPATIAL AND TEMPORAL VARIATION IN DISTRIBUTION RECORDS

4.1 INTRODUCTION

The dynamics of the distribution of the Flock Bronzewing Pigeon has received little critical analysis. Frith (1982) interpreted the scant available evidence from the published literature to suggest that Flock Bronzewing Pigeons periodically irrupt from permanently occupied habitat on the Barkly Tableland and adjacent regions. Such irruptions occurred in the aftermath of widespread rainfall in northern Australia in 1956 and 1967: after both years there were reports of the pigeons from areas beyond their normal range, including areas from which they had not formerly been known. After the 'abnormally wet year' of 1956 Flock Bronzewing Pigeons were reported from the Pilbara (Marshall and Drysdale 1962, Serventy and Whittell 1967) and Kimberley regions of Western Australia, coastal Queensland, and southern inland regions of New South Wales. Frith implies a similar movement strategy of explosive random dispersal to that previously ascribed to Grey Teal *Anas gracilis* (Frith 1962). Recent published studies on movements of individual Grey Teal suggests that movements are complex and idiosyncratic, and appear to be directed by prior knowledge of resource abundance at far-removed destination sites (Roshier 2009), and it is probable that Flock Bronzewing Pigeons exhibit similar capabilities. One difference may be that Grey Teal tend to move in pairs or small groups, whereas Flock Bronzewing Pigeons move in large coordinated flocks, though knowledge of the details of movement behaviour in this species is admittedly limited. Frith (1982) provides the only published description of an encounter with a travelling flock.

> Very large flocks were encountered to the west of the Stuart Highway south of Katherine (in the Northern Territory) and in that area I saw one such flock crossing the road. It was a kilometre from the front to the rear birds and the flock was 10 to 20 metres thick, flying on a front of perhaps 100 metres. There were many thousands in this mass of pigeons (Frith 1982).

Aside from the discussion of irruptive episodes by Frith (1982), and an historical perspective on the patterns of abundance in New South Wales by McAllan (1996), there has been no rigorous analysis of the temporal patterns of occurrence of the Flock Bronzewing Pigeon. In this chapter I examine spatial patterns within seven five-year intervals from 1971-2005, and in individual years with sufficient records, using a database of locality records compiled from various sources. The analysis is largely descriptive, and builds on the analysis of broad-scale spatial patterns reported in the previous chapter. I address the question whether available records provide evidence to support or refute the assertions of Parker (1969) and Frith (1982) that spatial reconfigurations of Flock Bronzewing Pigeon populations are centred on the Mitchell grasslands of the Barkly Tableland. I also examine the patterns of seasonal rainfall prior to reports of large aggregations of Flock Bronzewing Pigeons. Specifically, this chapter addresses the following research questions:

(1) Is there evidence that the distribution of Flock Bronzewing Pigeons is determined by rainfall patterns?

(2) What are the attributes of rainfall patterns prior to observations of large aggregations of this species?

4.2 METHODS

4.2.1 Temporal patterns of records of Flock Bronzewing Pigeons

Distribution records of Flock Bronzewing Pigeons were collected from various sources as described in the Methods section of Chapter 3. Most records include the year of observation, though for many records the observation is bracketed between dates which may occasionally span years. The frequency of records by year was graphed as a histogram.

4.2.2 Spatial variation in five-year intervals from 1971-2005

Records were allocated to seven five-year intervals from 1971-1975 to 2001-2005. For each five-year period the number of degree cells containing records was calculated using the 'completely contain' selection function of ArcGIS (ESRI 2004). Similarly, for each period the number of records and the number of degree cells containing records within the Lake Eyre Basin (LEB) was calculated, and the percentage of total records and cells within the LEB was calculated. The LEB encompasses much of the range of the Flock Bronzewing Pigeon in central Australia.

Average monthly rainfall in the LEB was calculated using interpolated rainfall grids provided by J. Kesteven of FSES at ANU. Grid files were available for the period from January 1970 to December 2006, at a continental extent and cell size of 0.05 decimal degrees. Monthly rainfall was estimated from monthly rainfall grids and intersections of 1,000 randomly placed points within the LEB. Data on monthly values of the Southern Oscillation Index were obtained from the Bureau of Meteorology, and presented as six month moving averages. Data on river heights and the occurrence of major flooding in Eyre Creek (Glengyle Station) were obtained from the Bureau of Meteorology.

4.2.3 Annual spatial variation

The distribution of Flock Bronzewing Pigeon records for years with a minimum of 30 records was overlain on maps of the mean standardised difference of seasonal rainfall (July to June) within the distribution of uniform cracking soils. Seasonal rainfall totals were used in preference to calendar year rainfall totals because of the predominance of summer rainfall in northern latitudes, and to align Flock Bronzewing Pigeon records with rainfall of the preceding rain season. Mean standardised difference was calculated as: MSD = [(seasonal rainfall – mean seasonal rainfall) / mean seasonal rainfall]. In ArcGIS polygons of uniform cracking soils were selected and converted to a grid file with the same extent and cell size as rainfall grids and allocated a value of 1. The MSD grid and the soils grid were multiplied to produce a layer of the distribution of uniform cracking soils attributed with the MSD values.

4.2.4 Rainfall patterns prior to records of large aggregations

Fourteen records of large aggregations of Flock Bronzewing Pigeons were selected from the historic literature and contemporary records to examine seasonal rainfall patterns preceding the observation. The records selected for examination of prior rainfall patterns were:

1. Carter (1902) reported an influx of Flock Bronzewing Pigeons into the coastal Pilbara region of Western Australia in January 1901.

> Enormous flocks of the pigeons were feeding on the freshly burnt ground, and about 8am they began to water at the pool in countless thousands. The preceding wet season was described as the wettest and 'best' (in a pastoral sense) ever known here (Carter 1902).

2. In September 1958 another influx of Flock Bronzewing Pigeons was reported in the Pilbara in Western Australia (Marshall and Drysdale 1962, Serventy and Whittell 1967).

> We saw about a thousand birds coming to drink at Mardie Pool . . . in the hour before sundown (Serventy and Whittell 1967).

3. In December 1993 large flocks of Flock Bronzewing Pigeons were observed at Brunette Downs Station on the Barkly Tableland in the Northern Territory.

> In December 1993 73,000 of probably 100,000 bronzewings were counted during their daily mass movements around the Lake Sylvester system (on Brunette Downs Station) (Jaensch 1994).

4. Large numbers of Flock Bronzewing Pigeons were recorded throughout mid to late 2006 on Alexandria Station on the Barkly Tableland of the Northern Territory by Ivan O'Donahoo (see Appendix 2).

5. In July 1958 huge flocks were encountered along the Barkly Highway west of Camooweal.

> Our vehicle disturbed them (an aggregation of pigeons) and they rose into the air in thousands, continuing to do so for the next mile of road (Williams 1970).

6. Berney (1928) quoted diary records of observations of 'immense' flocks on Manfred Downs Station in the Flinders River catchment in north Queensland in August 1901.

7. In early July 1994 Henry Nix (pers. comm.) recorded huge numbers of Flock Bronzewing Pigeons at a waterhole on the Saxby River on Lyrian Station in the Gulf region of Queensland. The following extract from his field notes describe possibly the largest aggregation of Flock Bronzewing Pigeons observed for many decades.

> Long stream of birds coming in to water as far north up the hole as my 10x40s could detect; counted 90-120 birds/sec passing in nearest stream i.e. 6,000 birds per minute, 360,000 per hour; streams for all but the hottest few hours of the day and continuous from about 4 pm to dark. Roar as birds settled on water. Whir/roar as birds took off from the plain (Nix 1994).

8. In June 1994 more than 15,000 Flock Bronzewing Pigeons were observed drinking at Spellery Creek near Julia Creek in central northern Queensland (Andrew and Eades 1994).

9. In November 2002 Mr Greg Campbell of Kidman Pastoral Company observed and photographed an enormous flock of Flock Bronzewing Pigeons drinking at Tomydonka waterhole on Glengyle Station in the Channel Country of far south-west Queensland (Figure 4.1). Large numbers were still present in the vicinity in December 2005 (Figure 4.2).

10. In August 2007 in the wake of extensive flooding in the Georgina system in January 2007, large numbers of Flock Bronzewing Pigeons were noted north of the township of Bedourie in far south-west Queensland (Angus Emmott pers. comm., Forsyth 2007).

11. In December 1990 large numbers were present on Astrebla Downs National Park in central Queensland.

> On 5 December 1990 . . . a flock estimated at 100,000 birds was seen flying and on the ground around No. 2 Bore (Stewart and Gynther 1993).

12. In September 1931 MacGillivray (1932) observed large numbers of Flock Bronzewing Pigeons on a small area of Hewart Downs Station in north-west New South Wales. McAllan

(1996) noted that the number of flocks mentioned by MacGillivray suggested that there were many hundreds if not thousands of birds involved.

13. An influx of Flock Bronzewing Pigeons into north-west New South Wales occurred in late 1992 and early 1993 in the wake of drought-breaking rains in western New South Wales. Nesting was observed in February 1993.

> Flocks of hundreds also began to lay in discrete patches in the Mitchell grass . . . They had chicks in a relatively short time and left the area during late March and early April (McAllan 1996).

14. In July 1995 Henry Nix (pers. comm.) observed large numbers of Flock Bronzewing Pigeons on Miranda Downs Station in the Gulf region at the base of Cape York in Queensland. His field notes record that large numbers were seen between Wild Rice Lagoon and Miranda Downs Homestead.

> . . . travelling across extensive grasslands with scattered trees along tracks from one bore to the next . . . flushed thousands of Flock Bronzewing Pigeons with individual flocks of 500-1,000 birds, both from grasslands and at watering points along the way (Nix 1995).

For all records monthly rainfall data from the nearest relevant Bureau of Meteorology station was extracted from databases supplied by the Rainman software package (Clewett *et al.* 2003). Seasonal rainfall totals were calculated and expressed as percentage rank by sorting seasonal rainfall totals in rank order and correcting for sample size.

Figure 4.1 Flock Bronzewing Pigeons drinking at Tomydonka waterhole, south-west Queensland, November 2002.

Photo by G. Campbell.

Figure 4.2 Flock Bronzewing Pigeons drinking at Miria waterhole, south-west Queensland, December 2005.

4.2.5 Caveats and interpretation

This analysis is an exploratory assessment of the interaction between rainfall patterns and the occurrence of Flock Bronzewing Pigeons. There are two caveats which need to be borne in mind when interpreting these results. Firstly, much of the data derive from volunteer-based surveys, principally for the Birds Australia atlas projects. Spatial and temporal biases in observer effort may potentially confound observed spatial patterns. Secondly, records are regarded as being equivalent, even though the biological significance of the observation of a single possibly vagrant bird differs from an observation of a flock of several thousand individuals. It is feasible that the provision of additional watering points by pastoralists has meant that the concentrations of pigeons observed in the past are less likely to occur, and that the absence of such flocks cannot be used as evidence of population decline. I do not attempt to discuss either the mechanisms of flock formation or the conservation significance of large flocks. There are no unbiased measures of relative abundance on which to base more rigorous analyses or to hypothesise on the frequency, or the significance of observations of large flocks.

4.3 RESULTS

The locality database contained 1,232 unique records of occurrence of the Flock Bronzewing Pigeon: of these 1,155 (93.6%) were attributed with the year of the record. The record is notable for its sparseness and patchiness prior to 1960 (Figure 4.3) - the majority of dated records occurred post-1960 (92.9%). There is a small cluster of records in the period from 1886-1908, and in the period 1930-1934: contemporary ornithological consensus feared the imminent demise of the species during this intervening period (Berney 1928, MacGillivray 1929). The record is boosted by pulses of observer activity due to the first and second atlas projects of Birds Australia in 1977-1981 (Blakers *et al.* 1984) and 1998-2002 (Barrett *et al.* 2003).

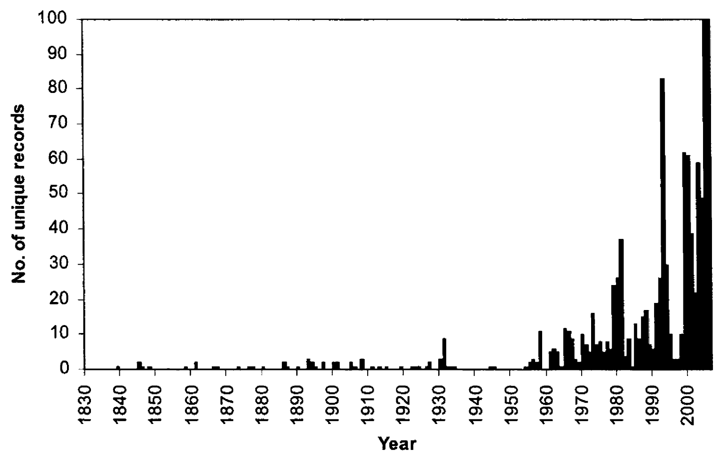


Figure 4.3 Frequency histogram of the number of unique database records dated by year.

Total number of records dated by year = 1,155. Totals for 2005 and 2006, 158 and 145 records.

4.3.1 Environmental variation

Years of major flooding in Eyre Creek system, months of high mean rainfall in the Lake Eyre Basin, and years of high Southern Oscillation Index (SOI) for the period 1971-2005 are shown in Table 4.1. Five of the nine years of major flooding in the Eyre Creek system occurred in the 1970s; as did four of the ten months of high average rainfall. There was substantial flooding in the Eyre Creek system in 2001 and early 2007. There were sustained periods of positive SOI in the 1970s and the late 1990s (Figure 4.4).

Table 4.1 Years of major flooding in the Eyre Creek system, months of significant rainfall in the Lake Eyre Basin and years of high Southern Oscillation Index.

Years of major flooding in Eyre Creek system (i.e. river height >4m)		
1971	1977	2001
1972	1991	
1974	1995	
1976	1997	
Months of high rainfall across LEB (i.e. mean rainfall >100mm)		
Jan 1974	Jan 1984	Feb 2000
Dec 1975	Mar 1989	Dec 2000
Feb 1976	Feb 1991	
Feb 1977	Feb 1997	
Years of high Southern Oscillation Index (i.e. SOI >10)		
1971	1975/76	2000
1972	1988/89	2001
1973/74	1998/99	

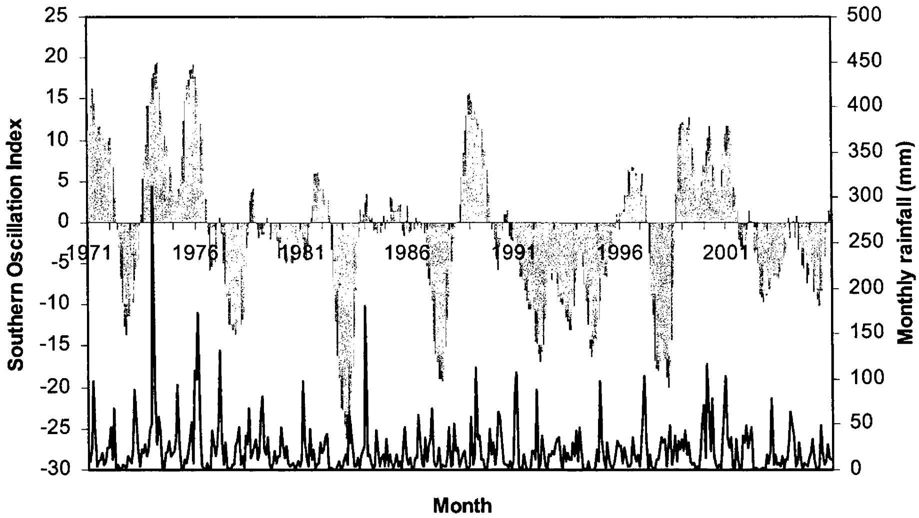


Figure 4.4 Monthly patterns of six monthly averaged Southern Oscillation Index and mean monthly rainfall in Lake Eyre Basin.

4.3.2 Spatial variation between five-year intervals

The spatial distribution of records within five-year intervals varied markedly between periods (Figure 4.5). In 1971-1975 and 1976-1980 records were mostly within the boundary of the Lake Eyre Basin, with 47.8% and 52.6% of all records; by contrast only 12.5% of records occurred within the LEB in 1981-1985; there were large numbers of records within LEB in both 1996-2000 and 2001-2005 (Table 4.2). Flock Bronzewing Pigeons were recorded in South Australia in all but one period, but were especially prominent in 1991-1995. Flock Bronzewing Pigeons were recorded from the Barkly region in the Northern Territory in all periods. Differences in the spatial distribution of records between periods correspond broadly to broad-scale patterns of rainfall. For example, there are many records within the LEB in the relatively wet period of 1976-1980 and relatively few in the dry period of 1981-1985.

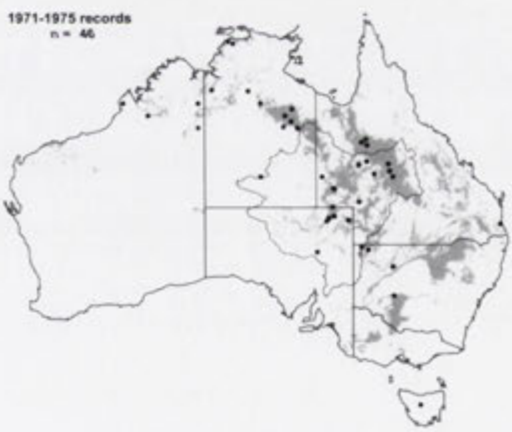
Table 4.2 Frequency of distribution records in seven five year intervals, and number and % number of records occurring within Lake Eyre Basin.

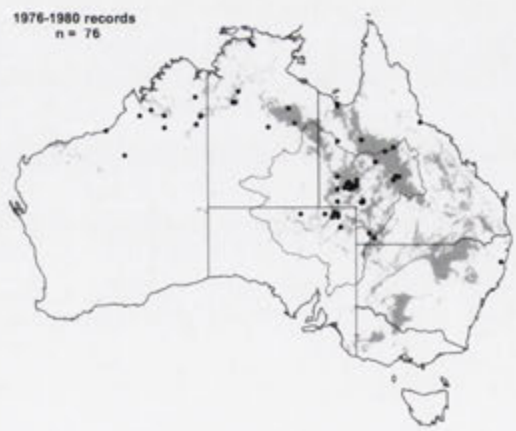
Period	# records	# cells	# LEB records	# LEB cells	% LEB records	% LEB cells
1971-1975	46	35	22	13	47.8	37.1
1976-1980	76	36	40	14	52.6	38.9
1981-1985	64	30	8	5	12.5	16.7
1986-1990	54	30	21	8	38.9	26.7
1991-1995	168	50	37	14	22.0	28.0
1996-2000	139	43	67	20	48.2	46.5
2001-2005	327	58	230	25	70.3	43.1

4.3.3 Annual spatial variation

The distribution of records within the years 1993 and 2000 suggest a relationship between occurrence of Flock Bronzewing Pigeons and seasonal rainfall patterns. In 1993 there was a proliferation of records in both the Barkly region in northern Australia, and central regions of South Australia and the western region of New South Wales. In 2000 records were largely confined to the Channel Country of western Queensland. This implies long-distance movement of populations to exploit variability in productivity across vast areas.

In three consecutive years from 1993 to 1995 there were records of very large numbers of birds at three locations at approximately the same latitude in northern Australia. In December 1993 Jaensch (1994) observed an estimated 100,000 Flock Bronzewing Pigeons on Brunette Downs Station on the Barkly Tableland; in June 1994 Nix (pers. comm.) observed possibly millions of pigeons watering at a waterhole on Lyrian Station north-west of Julia Creek in Queensland, and in July the following year observed many thousands on Miranda Downs Station in the south-east Gulf region. Seasonal rainfall in 1992/93 was above average on the Barkly Tableland and below average in the Gulf region; this pattern reversed the following year; and both were relatively poor the year following (Figure 4.6). It is possible that the sequence of observations is a result of pigeons tracking resources from year to year.





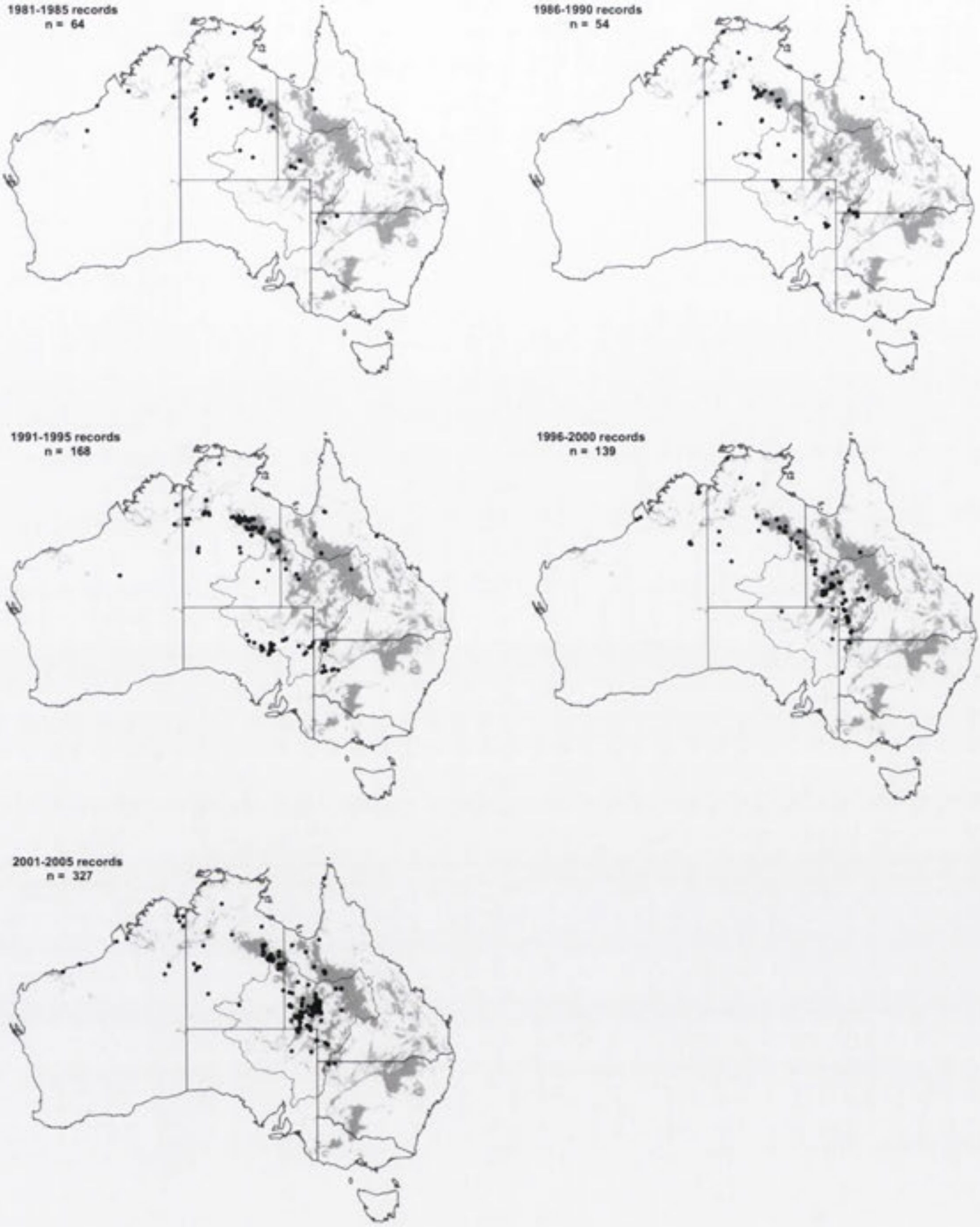
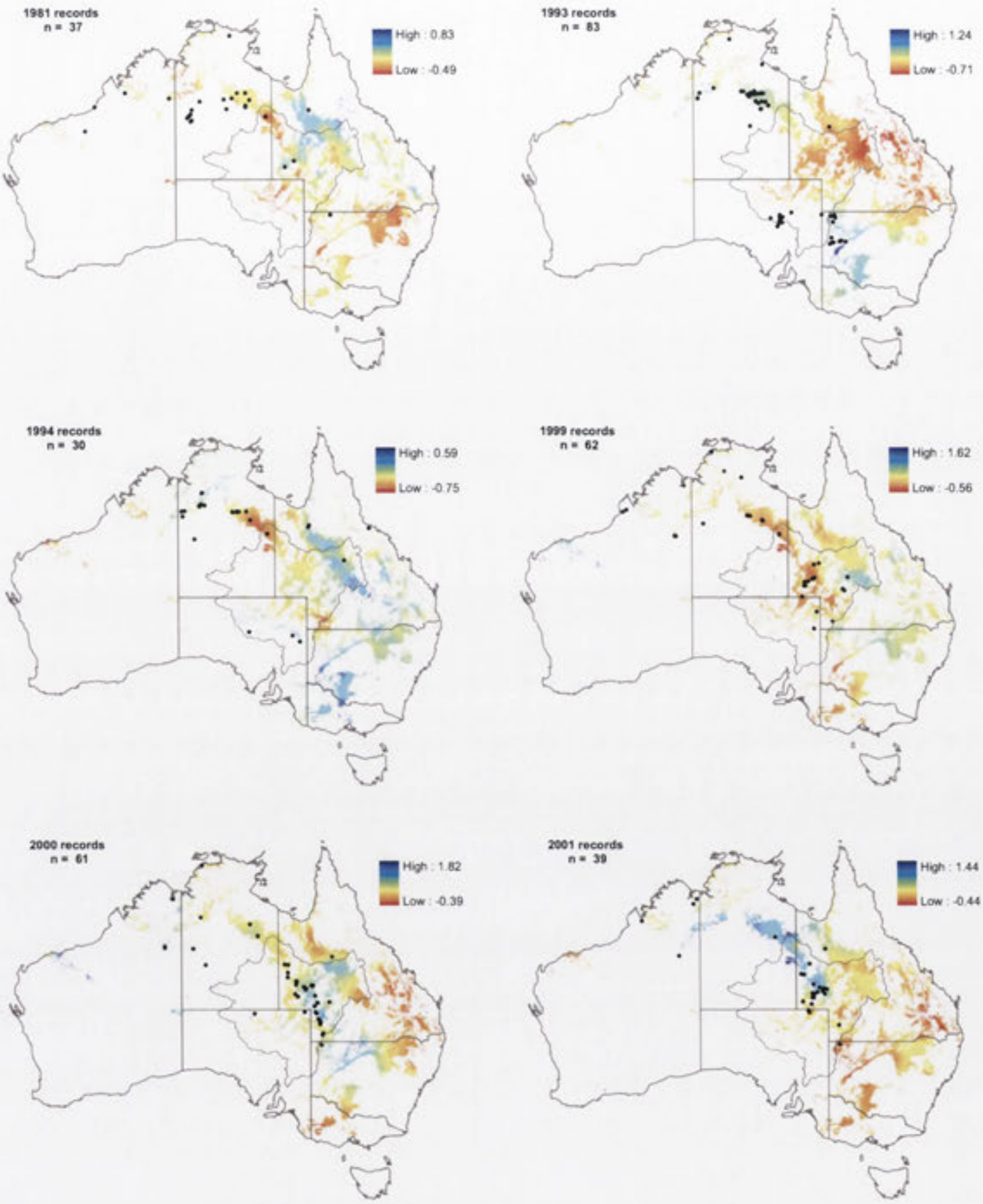


Figure 4.5 Distribution of locality records of Flock Bronzewing Pigeons in each of seven five-year intervals from 1971-2005.

Records overlain on distribution of uniform cracking soils. Boundary of Lake Eyre Basin shown.


1981 records
n = 37
High : 0.83
Low : -0.49
1993 records
n = 83
High : 1.24
Low : -0.71
1994 records
n = 30
High : 0.59
Low : -0.75
1999 records
n = 62
High : 1.62
Low : -0.56
2000 records
n = 61
High : 1.82
Low : -0.39
2001 records
n = 39
High : 1.44
Low : -0.44

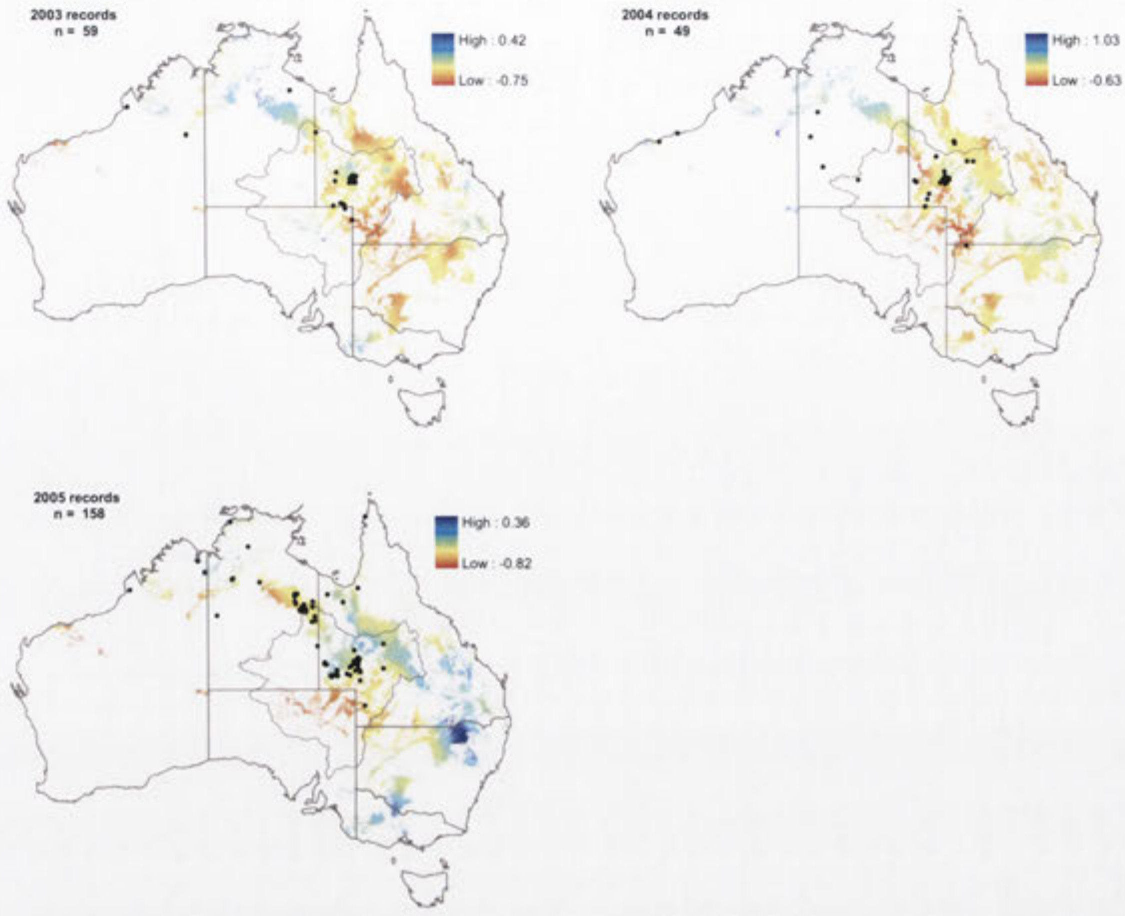


Figure 4.6 Distribution of locality records of Flock Bronzewing Pigeons in years with minimum of 30 Flock Bronzewing Pigeon records

Records overlain on mean standardised difference of annual seasonal rainfall on uniform cracking soils. Boundary of Lake Eyre Basin shown.

4.3.4 Rainfall patterns prior to records of large aggregations

Rainfall statistics for 14 records of large aggregations are shown in Table 4.3. Locations of these sites are shown in Figure 4.7. For most records rainfall in the preceding season was consistently above average, and for most exceeded 80^{th} percentile of rainfall ranks. Seasonal rainfall in the season prior was variable; six ranked $<20^{th}$ percentile of ranked seasonal rainfall (Figure 4.8). Data from Glengyle Station is anomalous and probably represents a response to favourable conditions in the preceding year: the seasonal rainfall in 2001/02 was 73 mm (rank 12.0%), in 2000/01 was 274 mm (rank 87.0%), and in 1990/00 was 199 mm (rank 69.6%).

Table 4.3 Annual seasonal rainfall statistics prior to observations of large aggregations of Flock Bronzewing Pigeons.

Site #	Rainfall station and number	State	Date	Source	Avg (mm)	Rainfall in prior year	Rainfall in year	% rank prior year	% rank year
1	Onslow Post Office #005106	WA	Jan 1901	Carter (1902)	277	99	708	14.0	97.5
2	Mardie #5008	WA	Sep 1958	Serventy and Whittell (1967)	276	105	551	16.8	92.4
3	Brunette Downs #015085	NT	Dec 1993	Jaensch (1994)	406	181	585	9.5	81.9
4	Alexandria Downs #015088	NT	mid-late2006	I. Odonahoo (pers. comm.)	396	278	632	29.8	90.9
5	Camooweal Post Office #037010	Qld	Jul 1958	Williams (1970)	397	518	491	83.5	80.0
6	Julia Creek (Manfred Downs) #029132	Qld	Aug 1901	Berney (1928)	486	181	563	3.3	71.7
7	Canobie (Cloncurry River) #029007	Qld	Jul 1994	H. Nix (pers. comm.)	520	414	569	32.5	68.4
8	Julia Creek Post Office #029025	Qld	Jun 1994	Andrew and Eades (1994)	465	435	622	50.0	79.8
9	Glengyle (Eyre Creek) #038009	Qld	Nov 2002	G. Campbell (pers. comm.)	169	274	73	87.0	12.0
10	Glengyle (Eyre Creek) #038009	Qld	Aug 2007	Forsyth (2007)	169	39	287	6.5	89.1
11	Coorabulka #038006	Qld	Dec 1990	Stewart and Gynther (1993)	214	196	361	53.2	88.1
12	Milparinka #046018	NSW	Sep 1931	MacGillivray (1932)	200	173	274	49.2	81.5
13	Milparinka #046018	NSW	Feb 1993	McAllan (1996)	200	102	290	14.5	85.5
14	Normanton Post Office #029041	Qld	Jul 1995	H. Nix (pers. comm.)	911	788	749	39.3	31.9
Mean					363.3	270.2	482.5	34.9	75.1

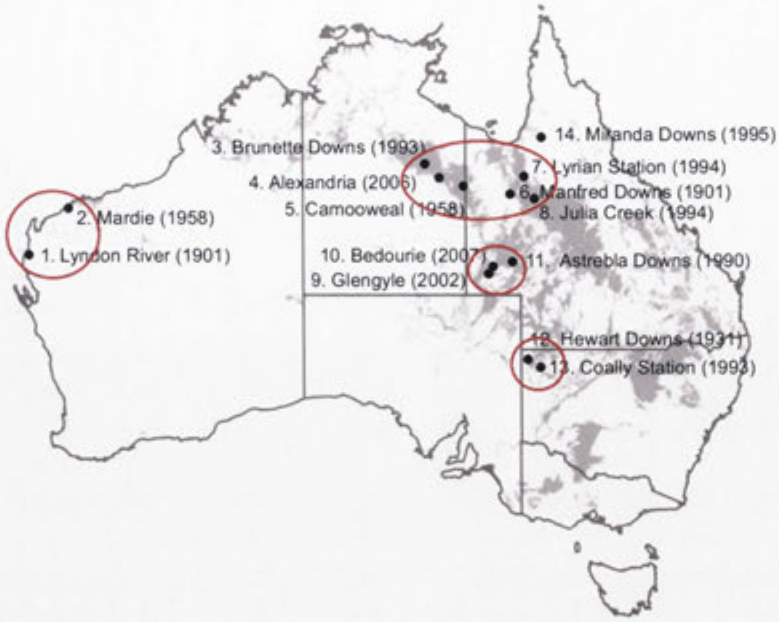


Figure 4.7 Distribution of sites with records of large aggregations of Flock Bronzewing Pigeons.

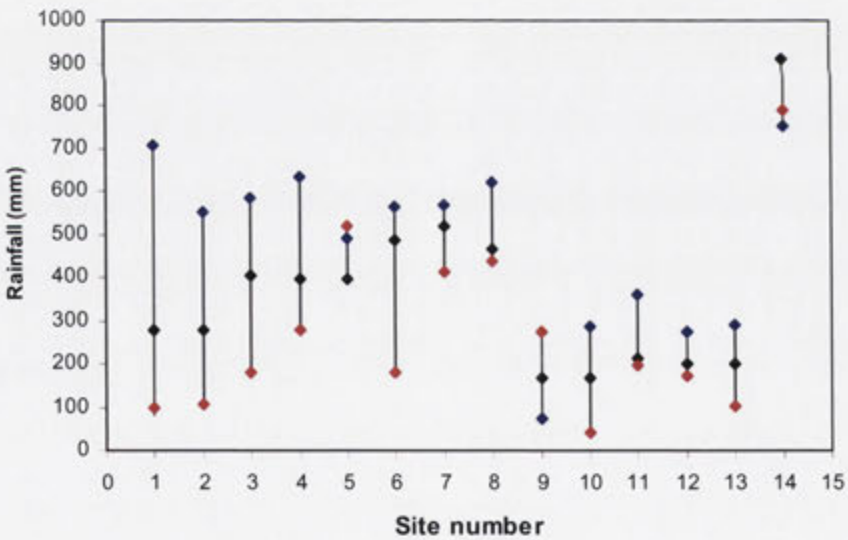


Figure 4.8 Seasonal rainfall statistics for fourteen observations of large aggregations of Flock Bronzewing Pigeons.

Blue symbol = seasonal rainfall immediately prior to observation; black symbol = mean seasonal rainfall; red symbol = season rainfall in year prior to observation.

4.4 DISCUSSION

These results suggest the movement model implied by Parker (1969) and Frith (1982) is probably a simplistic representation of a complex and dynamic system. The evidence suggests that rainfall events, or sequences of rainfall events, lead to reconfiguration of the continental population that is evident even when data are pooled within five-year blocks. The variability in the spatial distribution of records within five-year intervals is unlikely to be due solely to differences in the distribution of observers and must be, to some extent at least, a response to variation in the distribution of resources. For some individual years there appear to be strong correlations between the occurrence of Flock Bronzewing Pigeons and the distribution of resources as indexed by the distribution of rainfall in the preceding season. These years include 1993, 2000 and 2001. However, the sparseness and arbitrariness of the data precludes rigorous analysis: indeed there are years in which the opposite is true e.g. 1999. In summary, the locality database provides intriguing, but not unambiguous, evidence that occurrences of Flock Bronzewing Pigeons are predictably associated with favourable seasonal conditions.

Records of large aggregations of Flock Bronzewing Pigeons are frequently associated with a rare combination of events: well above average seasonal rainfall preceded by well below average seasonal rainfall. The historic literature includes a number of references to the arrival of birds or the presence of large aggregations following 'drought-breaking' rainfall events (MacGillivray 1932, McAllan 1996). The biological basis for this may be the response of ephemeral plants which exploit the lack of competition from perennial grasses in the early stages of recovery from drought and produce abundant seed. Similar responses in arid and semi-arid climates have been described on other continents (Holmgren *et al.* 2006).

Eleven of the fourteen records of large aggregations of Flock Bronzewing Pigeons share a common pattern of recent high seasonal rainfall, usually after drought. The two extreme examples both occur in the Pilbara region, though three of the six examples from the Barkly and adjacent regions are similar. Recent rainfall histories for three of the fourteen examples present a somewhat different pattern, though at least two of these (Camooweal 1958, and Glengyle Station 2002) might be explained by the persistence of local populations following above average rainfall more than one year previously. According to Frith (1982) the year 1956 was an abnormally wet year in northern and eastern Australia, and there was widespread major flooding in the Eyre Creek system in 2001.

The movement responses of Flock Bronzewing Pigeons are likely to be more complex than is implied by the simple model of Parker (1969) and Frith (1982). There are clues that dispersive movements are not undirected, stochastic behaviours, but lead to occupation of habitats with a high probability of survival and reproductive success. There are several records of vagrants arriving in marginal coastal habitats (Crawford 1972), but these rarely involve large numbers of individuals and contrast with the drought refugee movements of some species such as Letter-winged Kite *Elanus scriptus* (Hollands 1979). Secondly, the importance of habitats within the Channel Country of far-south-west Queensland has been under-estimated. Both the Barkly and Channel Country regions were identified as significant habitat by analyses in previous chapters. Occupation of the Channel Country is probably driven by the replenishment of seed resources by the response of vegetation following episodic major flooding events in the Georgina and Diamantina river systems, as occurred in 2001 and 2007.

The dynamics of the patterns of occupation and the patterns of seed dynamics in these two regions (Barkly and Channel Country) deserve further study. In particular, it would be worth discovering whether these patterns are predominantly annual or multi-annual. Anecdotal information supplied by the manager of Glengyle Station suggests that Flock Bronzewing Pigeons were frequent regular visitors, arriving in numbers from early winter and reaching maximum numbers in early summer, but mostly absent during wetter summer months. Pigeons in this area are known to rely on seed of Common Verbine *Cullen cinereum* and the sedge *Schoenoplectus dissachanthus*, both of which are abundant in inundated habitats during the post-flooding drying phase, and produce abundant seed. Do single flood events produce persistent seed banks available to foraging granivorous birds over several years? Conversely, are seed banks predominantly annual and are pigeons reliant on summer rainfall or minor flood events to generate adequate seed resources? Further studies are required to address these questions.

4.5 SUMMARY OF FINDINGS AND CONCLUSIONS

Spatial and temporal variation in distribution records of the Flock Bronzewing Pigeon was examined using database records pooled within seven five-year intervals from 1971-2005, and for nine years with a minimum number of 30 records. Potential spatial and temporal biases in observer effort confound rigorous analysis of spatial variation, and conclusions should be regarded as tentative. With this caveat in mind, distributional patterns were assessed in relation to spatial and temporal variation in rainfall.

Over 40% of database records of Flock Bronzewing Pigeons occurred within the Lake Eyre Basin of inland Australia. Whilst data are sparse for some periods, there is a general trend for relatively large numbers of records in the Lake Eyre Basin in periods following high rainfall, and for relatively few records in sustained low rainfall periods; and to be continuously present in the Barkly region even in low rainfall periods. Data suggest that the central region of the Lake Eyre Basin provides important habitat in the periods 1976-1980, 1996-2000, 2001-2005: these periods correspond to the occurrence of episodic floods in Channel Country rivers, particularly in the Georgina River and Eyre Creek system.

Relationships between landscape productivity and occurrence of Flock Bronzewing Pigeons were examined graphically by overlaying distribution records on maps of the mean standardised difference of seasonal annual rainfall. Records tended to occur in regions receiving high seasonal rainfall e.g. 1993, 2000, 2001, but the reverse was frequently also true, and there are several records for example in the Barkly region during dry years. Database records do not provide an unambiguous indication that the distribution of Flock Bronzewing Pigeons is determined by recent seasonal rainfall.

Analysis of the rainfall patterns prior to observations of large aggregations suggest that aggregations occur following years of above average seasonal rainfall, which are frequently preceded by drought years.

Chapter 5: A COMMUNITY-BASED SURVEY OF THE DISTRIBUTION AND ABUNDANCE OF THE FLOCK BRONZEWING PIGEON

5.1 INTRODUCTION

Mail-out surveys have been used previously in Australia to collect data on ecological phenomena including the local distribution of taxa of conservation significance (Lunney *et al.* 1997), patterns of occurrence of nomadic birds across broad spatial scales (Wyndham 1983, Ziembicki and Woinarski 2007), and rare events such as the occurrence of irruptive rodents (Carstairs 1974). The method can be applied when the target species or phenomena are familiar (e.g. koala, bustard) or unmistakeable features of the environment (e.g. rat plagues). The Flock Bronzewing Pigeon may be a suitable candidate to attempt to elicit information from the rangeland community. They are relatively large, are conspicuous especially when in large flocks, and form part of the folk-lore of inland Australia (Marshall and Drysdale 1962). There are considerable advantages in harvesting information from the rangeland community: many are astute observers of natural phenomena, having spent much of their working lives traversing suitable habitat, are well-placed to observe transient phenomena, and potentially offer a temporal perspective spanning several decades. Indeed, there are few other options to gather ecological information on this species in the remote, sparsely populated areas of northern and central Australia (Mac Nally *et al.* 2004).

The aims of the survey were to gather information on the temporal patterns of occurrence; to assess local status and perceptions of reasons for change in status; and to investigate the relationships between grazing practice, potential predators and the probability of occurrence of Flock Bronzewing Pigeons. The survey also sought to identify potential participants in a future intensive survey of 18 months duration (presented in Chapter 6). Specifically, this chapter addresses the following research questions:

(1) What are the intra- and inter-annual patterns of abundance of the Flock Bronzewing Pigeon?

(2) What are the environmental correlates of patterns of abundance of Flock Bronzewing Pigeons?

5.2 METHODS

5.2.1 Pre-survey publicity

Prior to the commencement of the mail-out survey in November 2005 I advertised the survey using various media including rural newspapers, natural resource management newsletters, the rural show circuit and radio interviews. Articles were published in the rural newspaper 'Queensland Country Life' on 20th October 2005 (Figure 5.1); in 'Savanna Links', newsletter of the Co-operative Research Centre for Tropical Savannas in early 2005; and in 'Savannah News', newsletter of the Gulf region natural resource management group in June 2005. Desert Channels Queensland assisted with a display for the Queensland rural show circuit, and issued a media release on the project. An interview on the ABC Country Hour program was broadcast in the Northern Territory and throughout rural Queensland. Pre-survey publicity succeeded in raising awareness of the survey and interest in the project throughout the rural community.

Have you seen this bird lately?

Qld Country Life 20/10/05

PASTORALISTS throughout northern and central rangelands can help track one of Australia's most fascinating nomadic birds by taking part in a survey soon to arrive in the mail.

A survey will be mailed to pastoralists throughout northern and central Australia during November/December, seeking information on whether flock bronzewing pigeons have been seen on their property.

Peter Dostine, Australian National University, said the aim of the survey was to find out where these birds are still common and why.

"People can make a significant contribution to our understanding of the birds through the survey, by providing information on whether these birds have been seen, or are still seen on their properties," he said.

Some birds will be fitted with satellite transmitters to provide data on large-scale movements and to identify what types of habitat they are using throughout the year.

The information gathered from the survey will be summarised and presented on the Bird Survey page of the Tropical Savannas CRC website.

The survey form can also be completed online.

● Contact Peter Dostine (08) 8944 8475 or peter.dostine@nt.gov.au

Figure 5.1 Article alerting residents to mail-out survey, published in Queensland rural media in October 2005.

5.2.2 Survey delivery

Survey forms were mailed to rangeland users in pastoral zones throughout the range of the Flock Bronzewing Pigeon in November 2005. The mail-out included a letter with a brief description of the project, black and white images of Flock Bronzewing Pigeons and other pigeon species which may be potentially confused (i.e. Crested Pigeon *Ocyphaps lophotes* and Common Bronzewing *Phaps chalcoptera*), the questionnaire, and a reply paid envelope. In the Northern Territory, Western Australia and South Australia surveys were mailed to addresses provided by the pastoral lands boards. Pastoralist addresses were not available for Queensland or New South Wales. For Queensland I used a combination of addresses known from other sources, and the 'Atlas of Queensland and Northern Territory Pastoral Stations' (Alick and Alick 2000) to locate properties and identify probable postal addresses of most pastoral properties within the zone west of a line drawn from Bourke in New South Wales, to Charleville, Barcaldine, Hughenden and Croydon in north Queensland. In western New South Wales I used unaddressed mail service and roadside postal delivery from the townships of Bourke, Broken Hill, Menindee, Tibooburra, Wanaaring and White Cliffs. The survey was also available on-line on a web-page linked to the Co-operative Research Centre for Tropical Savannas.

Table 5.1 Questions on survey forms sent to pastoralists throughout the range of the Flock Bronzewing Pigeon in late 2005.

#	Survey question
	Property name, state, geographic coordinates (if known), date and length of time in the region.
1	Have you ever seen Flock Pigeons on your property?
2	(a) In which months are they mostly seen? (circle month(s) from January to December) (b) In the past 12 months how abundant have Flock Pigeons been in your area? Have you seen: None, Few small flocks, Many small flocks, Few large flocks, Many large flocks (n.b. few <5, small <20)? (c) On how many occasions have you seen Flock Pigeons over the past 12 months? (d) Can you give an estimate of the total number of birds seen over the past 12 months?
3	Can you recall which years or periods which years have been best for Flock Pigeons in your area? (circle best year(s) from 1970 to 2005).
4	(a) Have you seen signs of Flock Pigeons breeding in your area? (b) When did you see this? (circle year(s) from 1970 to 2005) (c) In which months? (circle month(s) from January to December) (d) What did you see: Nest with eggs, Chicks, Distraction display, (on ground near nest), Male display flight (wings held in sharp V while gliding)?
5	Are good numbers of Flock Pigeons and/or signs of breeding associated with: Good rainfall in your area, Drought in your area, Fire, Drought elsewhere, Grass seeding, Receding floodwaters?
6	(a) Have numbers of Flock Pigeons increased or decreased in your region in your time? (Increased, Decreased, No change) (b) Can you suggest reasons for any observed changes?
7	(a) How abundant are feral cats in your area? Are they: Absent, Present in low numbers, Very abundant? (b) How abundant are foxes in your area? Are they: Absent, Present in low numbers, Very abundant? (c) How abundant are dingos/wild dogs in your area? Are they: Absent, Present in low numbers, Very abundant?
8	In the past 12 months has rainfall on your property been: Well below average, Below average, Average, Above average, Well above average?
9	What is the main agricultural activity on your property: Sheep, Cattle, Cropping?
10	Would you be willing to be contacted to help provide information on the local abundance of Flock Pigeons in your area throughout 2006?
	On a scale of 1 to 10 how do you rate your confidence in correctly identifying Flock Pigeons (1 = low, 10 = high)?

5.2.3 Survey questions

The survey questions (Table 5.1) are modelled on a mail-out survey conducted in 2002/03 and reported by Ziembicki and Woinarski (2007) on the occurrence of the Australian Bustard *Ardeotis australis* and the Flock Bronzewing Pigeon. Some data from this earlier survey have been used in analyses here.

5.2.4 Spatial patterns

The spatial distribution of records of presence/absence of Flock Bronzewing Pigeons, types of pastoral use and predator occurrence were mapped using ArcGIS (ESRI 2004) for each property using coordinates of the station homestead derived from the Australian Geographic Place Names Gazetteer (www.ga.gov.au/map/names/). Spatial data are overlain on a one-degree grid showing the spatial extent of the survey, and composite data comprising VAST land disturbance indices (Thackway and Lesslie 2005) within the modelled distribution (P>0.75) of Flock Bronzewing Pigeons. The frequency of survey responses by state, IBRA bioregions and drainage basin was derived using ArcGIS.

5.2.5 Intra-annual patterns of occurrence

Data are presented separately for the 2002/03 and 2005 mail-out surveys. The earlier survey asked respondents to identify the best season or seasons for Flock Bronzewing Pigeons i.e. Spring, Summer, Autumn, Winter. The latter survey asked respondents to identify the best month(s). Months identified as best for Flock Bronzewing Pigeons on each property were summed for all data, and separately for two southern Queensland catchments (Cooper Creek and Diamantina River) and a northern Queensland catchment (Flinders River). For each property, data were the mid-point of the span of consecutive months where multiple months were identified; where an even number of months were identified, the two centre months each scored 0.5. Responses which identified all 12 months were removed from the analysis. Data are presented as frequency histograms for each catchment.

5.2.6 Inter-annual patterns of occurrence

Respondents were asked to identify which years or periods of years were best for Flock Bronzewing Pigeons between the years of 1970-2005. These data are presented for all respondents and for those with at least 15, 25 and 35 years in their local area. The areal extent of catchments receiving above average rainfall in categories: 1-1.5 times average seasonal rainfall, 1.5-2 times average seasonal rainfall and 2+ times average seasonal rainfall; was calculated from interpolated digital rainfall surfaces from 1970 to 2006 using ArcGIS (ESRI 2004). Rainfall surfaces were provided by J. Kesteven of FSES at ANU . Catchments covered the area from which most survey responses were received and included Cooper Creek, and the Flinders, Diamantina and Georgina Rivers. Data on the Southern Oscillation Index were obtained from Bureau of Meteorology records.

5.2.7 Breeding observations

Respondents were requested to identify years, months and types of signs of breeding activity observed on their property. Breeding signs included nest with eggs, nest with chicks, distraction display, and male display flight. Nests are usually positioned beneath the shelter of a perennial grass tussock (frequently Hoop Mitchell Grass *Astrebla elymoides*) or shrub, and can be very difficult to locate. Nests are frequently located after a sitting bird has been flushed from the nest by passing stock. In the aerial display flight, birds adopt an erect winged posture and drop momentarily in flight with an audible distinctive change in the cadence of wing beats. The most reliable indicator of breeding activity in the local area is the presence of birds in distinctive juvenile plumage. This requires deliberate inspection of flocks as they gather at watering points. Data for each sign of breeding were tabulated. For each respondent on this question, the mid-point of the span of months in which breeding activity was observed was identified and tallied.

5.2.8 Environmental correlates

Respondents were asked to identify which bioclimatic features were associated with good numbers of Flock Bronzewing Pigeons in their area, including good rainfall, local drought, drought elsewhere, presence of seeding grasses, receding floodwaters and fire. Data for each were tallied and presented as a frequency histogram.

5.2.9 Threatening processes

Respondents were asked to consider whether Flock Bronzewing Pigeons had increased or decreased in abundance in their area, and to suggest possible reasons for any perceived change in abundance.

5.2.10 Potential predators

Respondents were asked to subjectively rate the abundance of potential predators of ground-nesting birds including feral cats, foxes and dingos or wild dogs in their area. Data are presented as percent frequency by land use type (Sheep, Sheep and cattle, Cattle) for both foxes and dingos/wild dogs. Feral cats were virtually ubiquitous and the data are not presented. Spatial data were mapped as described previously. Binomial modelling was used to examine the relationship between pastoral land use and the probability of occurrence of foxes and dingos/wild dogs.

5.2.11 Effect of grazing type

The relationship between the occurrence of Flock Bronzewing Pigeons and the type of pastoral land use was modelled using generalised linear modelling in the R software package (R Development Core Team 2008), using binomial errors and the logit link function. The dependent variable was the presence of Flock Bronzewing Pigeon on a property; independent variables were categorical variable Land Use (Sheep, Sheep & cattle, Cattle), and the continuous variable habitat score (0-1) derived from each of four spatial models from Chapter 3. Habitat score is the estimated probability of occurrence derived from predictive modelling of fauna database records. The Akaike Information Criterion corrected for sample size (AIC_c) was used to assess model support. Further details of model selection are given in section 3.2.7.

5.2.12 Caveats and interpretation

There are several caveats attached to interpretation of analyses of these data. Firstly, there is unavoidable variation between observers in their ecological knowledge, reliability and length of residency. These factors were documented, but not explicitly considered in most analyses. There is also likely to be less precision associated with older records. Secondly, there may be some reticence by respondents to reveal that Flock Bronzewing Pigeons have decreased or disappeared from their property, and consequently a bias towards inflating the recent distribution of the species. Such biases are probably minor and do not seriously compromise conclusions drawn from analyses. On the other hand, this species is reasonably likely to be unambiguously identified, especially so given that comparative photos were given for the most similar species.

5.3 RESULTS

5.3.1 Survey response

Over 2,700 survey letters were distributed to rangeland users. Of these 407 were returned, though two survey responses were received from the same property. Response rates from each state/territory ranged from 10.8-17.2%, the overall response was 14.9% (Table 5.2). Not all survey responses provided the property name or contact details and consequently could not be mapped. Survey responses were not uniformly distributed (Figure 5.2) and were concentrated in a region of central Queensland with a relatively high density of pastoral properties.

Table 5.2 Results of mail-out survey to pastoral landholders by state/territory.

	NT	SA	WA	NSW	Qld	No state	All states
# surveys	218	320	197	461	1,537		2,733
# responses	34	54	29	50	229	10	406
% responses	15.6	17.2	14.7	10.8	14.9		14.9

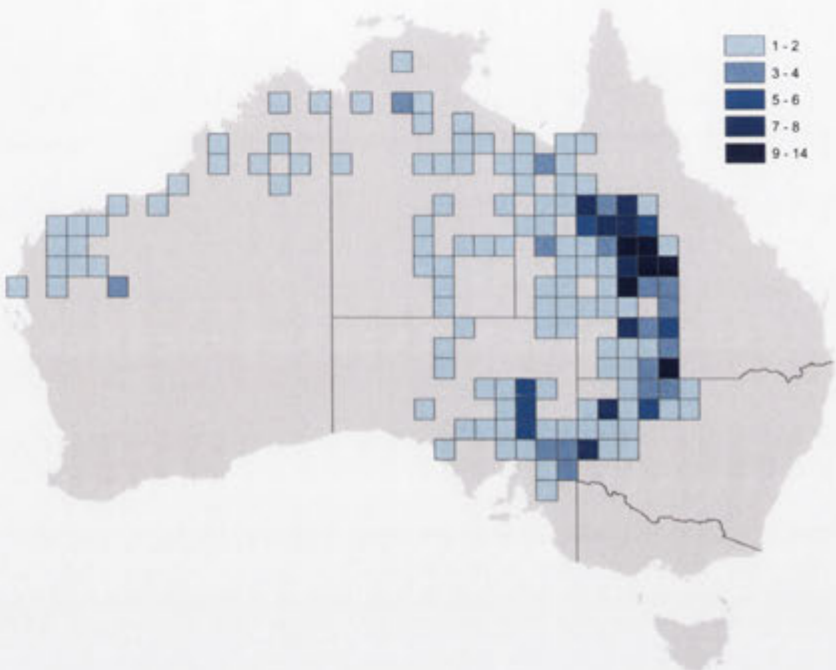


Figure 5.2 The number of survey forms received from pastoral properties by degree cell.

5.3.2 Attributes of respondents: time in area, and confidence scores

Of 295 respondents to provide data on the number of years in the local area, the majority had been on the property for a considerable length of time (Figure 5.3). For example, 72.2% had been in the area for 10 years; 61.4% had been in the area for 20 years; and 48.5% had been in the area for 30 years. The median time in the area was 26 years. Of 316 respondents to rate their confidence in correctly identifying Flock Bronzewing Pigeons, 255 (80.7%) scored at least 7 out of 10, and of the 141 respondents who indicated that Flock Bronzewing Pigeons had been present on their property 130 (89.8%) scored at least 7 out of 10 (Figure 5.4). The majority of respondents had significant local experience and by their own assessment were confident in their ability to correctly identify the species of interest. The data were not filtered on the basis of time in area or confidence score, except for analyses of long-term patterns of abundance.

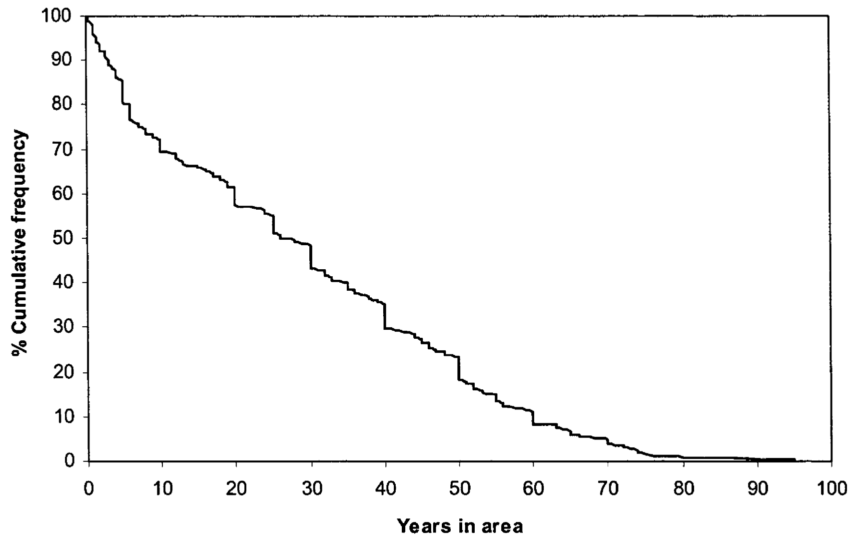


Figure 5.3 Percent cumulative frequency of time in the local area of respondents to mail-out survey.

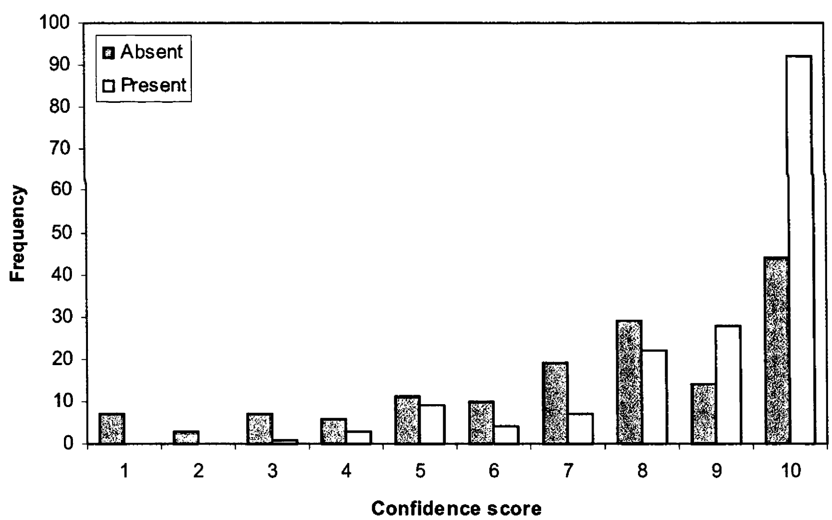


Figure 5.4 Frequency histogram of score of confidence in correctly identifying Flock Bronzewing Pigeons.

5.3.3 Spatial patterns

The results of the mail-out survey largely corroborate the results of the distributional modelling of faunal database records, albeit with some spatial bias due to the concentration of respondents in central western Queensland. From the mail-out responses, reports of Flock Bronzewing Pigeons cluster within the relatively closely settled region of central Queensland within the range predicted by spatial modelling (Figure 5.5). Reports elsewhere, including the Channel Country in south-west Queensland and the Barkly Tableland in the Northern Territory are sparse. Respondents indicating that Flock Bronzewing Pigeons were not present mostly occur within an arc on the south-eastern quadrant of the survey area outside the predicted range (Figure 5.6). Queensland provided the majority of the returned survey forms, and the highest percentage of reports of occurrence of Flock Bronzewing Pigeons (48.5%) (Table 5.3). Most occurred within a region mapped under the VAST categorisation as modified or transformed. The highest number of survey returns were from the Mitchell Grass Downs bioregion (35.2%); the highest percentage of reports of occurrence were from Channel Country (68.4%), Gulf Plains (63.2%) and Mitchell Grass Downs (61.2%) (Table 5.4). On a drainage basin scale, the highest number of survey responses were from the Cooper Creek catchment (25.6%), the Flinders Rivers catchment (10.9%) and the Diamantina River catchment (6.0%); the highest percentage of reports of occurrence (from those with at least 15 reports) were the Diamantina River (72.7%), Flinders River (65.0%), Georgina River (53.3%) and Cooper Creek (53.2%) (Table 5.5).

Table 5.3 Frequency of reports of Flock Bronzewing Pigeons on pastoral properties by state.

Status	NT	SA	WA	NSW	Qld	No state	All states
Ever seen on property	9	9	6	2	111	2	146
Not ever seen on property	26	45	23	48	118	7	260
% total seen on property	25.7	16.7	20.7	4.0	48.5		36.0

Table 5.4 Frequency of reports of Flock Bronzewing Pigeons on pastoral properties by IBRA bioregion.

% total responses = % number responses per IBRA bioregion / 366; % total present = % number present / number responses per IBRA bioregion, n = 366.

IBRA bioregion name	Absent	Present	Total	% total responses	% total present
Broken Hill Complex	17	1	18	4.9	5.6
Burt Plain	3	1	4	1.1	25.0
Carnarvon	1	1	2	0.5	50.0
Central Kimberley	2		2	0.5	0.0
Channel Country	6	13	19	5.2	68.4
Cobar Peneplain	1		1	0.3	0.0
Dampierland	2	2	4	1.1	50.0
Darling Riverine Plains	4		4	1.1	0.0
Davenport Murchison Range		3	3	0.8	100.0
Desert Uplands	3	1	4	1.1	25.0
Eyre and Yorke Blocks	1		1	0.3	0.0
Finke	3		3	0.8	0.0
Flinders Lofty Block	14	3	17	4.6	17.6
Gascoyne	7	1	8	2.2	12.5
Gawler	10	2	12	3.3	16.7
Gulf Fall and Uplands	3		3	0.8	0.0
Gulf Plains	7	12	19	5.2	63.2
MacDonnell Ranges	2		2	0.5	0.0
Mitchell Grass Downs	50	79	129	35.2	61.2
Mount Isa Inlier	3	2	5	1.4	40.0
Mulga Lands	51	9	60	16.4	15.0
Murray Darling Depression	11		11	3.0	0.0
Northern Kimberley	1		1	0.3	0.0
Ord Victoria Plain	4		4	1.1	0.0
Pilbara	6	2	8	2.2	25.0
Pine Creek	1		1	0.3	0.0
Riverina	1		1	0.3	0.0
Simpson Strzelecki Dunefields	4	1	5	1.4	20.0
Stony Plains	5	2	7	1.9	28.6
Sturt Plateau	5	1	6	1.6	16.7
Victoria Bonaparte	1	1	2	0.5	50.0
Number of properties	229	137	366		

Table 5.5 Frequency of reports of Flock Bronzewing Pigeons on pastoral properties by drainage basin.

% total responses = % number responses per basin / 366; % total present = % number present / number responses per basin, n = 367.

Basin name	Absent	Present	Total	% total responses	% total present
Ashburton River	3	2	5	1.4	40.0
Barkly	1	5	6	1.6	83.3
Bulloo River	9	3	12	3.3	25.0
Burt		1	1	0.3	100.0
Condamine-Culgoa Rivers	24	5	29	7.9	17.2
Cooper Creek	44	50	94	25.6	53.2
Darling River	13		13	3.5	0.0
De Grey River	1		1	0.3	0.0
Diamantina River	6	16	22	6.0	72.7
Drysdale River	1		1	0.3	0.0
Finke River	5		5	1.4	0.0
Fitzroy River (WA)	3	2	5	1.4	40.0
Flinders River	14	26	40	10.9	65.0
Fortescue River	1		1	0.3	0.0
Gairdner	6	1	7	1.9	14.3
Gascoyne River	4		4	1.1	0.0
Georgina River	7	8	15	4.1	53.3
Hay River	1		1	0.3	0.0
Lake Bancannia	8	2	10	2.7	20.0
Lake Frome	15	5	20	5.4	25.0
Lake Torrens	7	1	8	2.2	12.5
Leichhardt River	1	2	3	0.8	66.7
Lennard River	1		1	0.3	0.0
Lower Murray River	12		12	3.3	0.0
Lyndon-Minilya Rivers	2		2	0.5	0.0
Mackay	2		2	0.5	0.0
Macquarie-Bogan Rivers	1		1	0.3	0.0
Mambray Coast	2		2	0.5	0.0
Mary River (WA)	1		1	0.3	0.0
McArthur River	1		1	0.3	0.0
Nicholson River	3	2	5	1.4	40.0
Norman River	1		1	0.3	0.0
Onslow Coast	3		3	0.8	0.0
Ord River	2		2	0.5	0.0
Paroo River	11		11	3.0	0.0
Port Hedland Coast	1	2	3	0.8	66.7
Roper River	5		5	1.4	0.0
Sandy Desert	1		1	0.3	0.0
Settlement Creek	1		1	0.3	0.0
Todd River	2		2	0.5	0.0
Victoria River		1	1	0.3	100.0
Warrego River	2		2	0.5	0.0
Willochra Creek		1	1	0.3	100.0
Wiso	2	2	4	1.1	50.0
Number of properties	230	137	367		

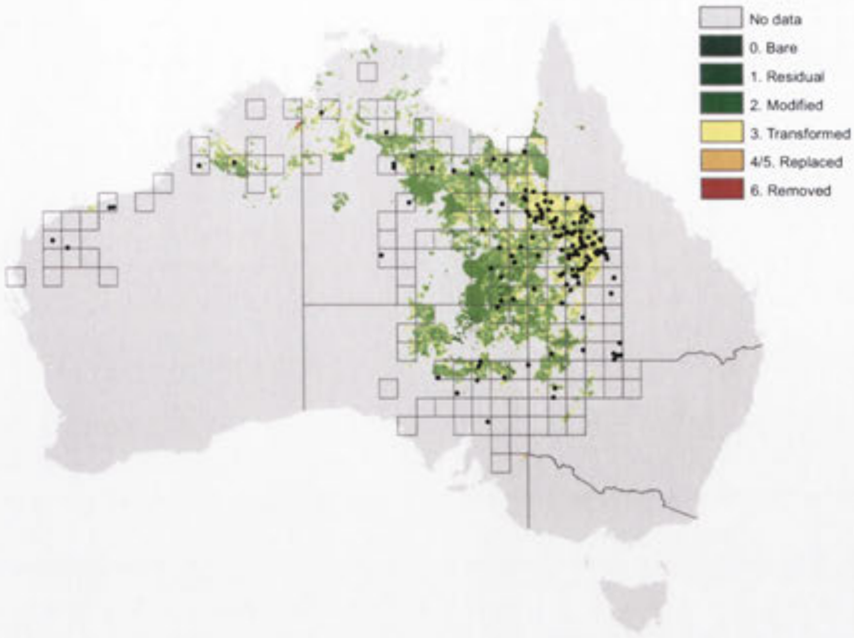


Figure 5.5 Distribution of respondents indicating that Flock Bronzewing Pigeons had been seen on their property.

Spatial extent of survey indicated by one-degree grid cells. The distribution of VAST land disturbance indices within predicted distribution (Model 1) of Flock Bronzewing Pigeons also shown.

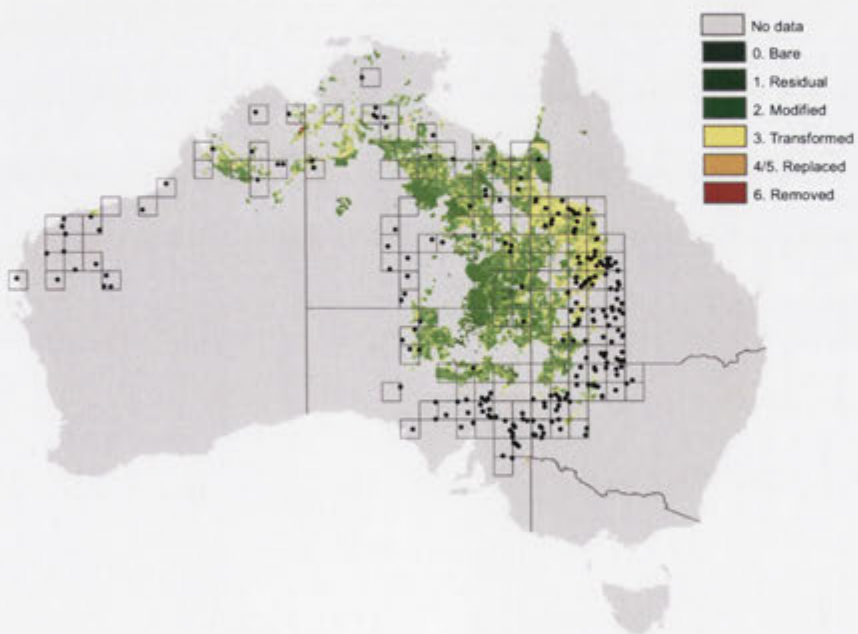


Figure 5.6 Distribution of respondents indicating that Flock Bronzewing Pigeons had not been seen on their property.

Spatial extent of survey indicated by one-degree grid cells. The distribution of VAST land disturbance indices within predicted distribution (Model 1) of Flock Bronzewing Pigeons also shown.

5.3.4 Intra-annual temporal patterns

In the 12 month period prior to the 2005 survey most of 146 respondents reported that Flock Bronzewing pigeons were present in 'few small flocks' (Table 5.6). These terms were defined as few, less than five occasions; and small flocks, less than 20 birds.

Table 5.6 Frequency of abundance classes reported in 12 month period prior to mail-out survey.

Abundance criteria	Frequency
None	41
Few small flocks	70.5
Many small flocks	8
Few large flocks	19.5
Many large flocks	5

Data from the 2005 mail-out survey suggest seasonal differences in the patterns of occurrence between northern and southern portions of their range in Queensland (Figure 5.7). There is a winter dry season nadir in reported occurrences on properties in the southern Cooper Creek catchment, and a corresponding peak in occurrences in the northern Flinders catchment. There is no clear monthly pattern in occurrences on properties in the Diamantina catchment.

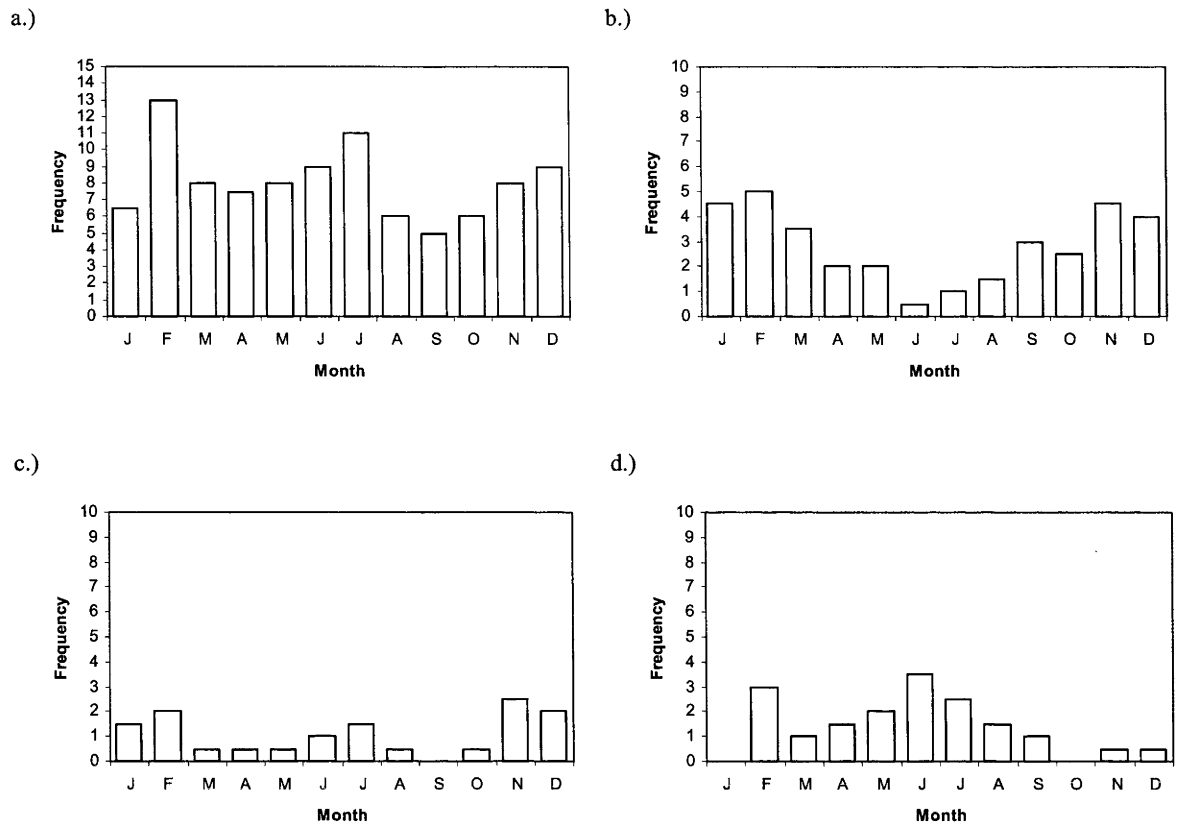


Figure 5.7 Frequency of reports of monthly occurrence by property.

(a) all data (n = 97); (b) Cooper Creek catchment (n = 34); (c) Diamantina River catchment (n = 13); and (d) Flinders River catchment (n = 17).

Data from the 2002/03 survey also suggest geographic differences in the seasonal patterns of occurrence (Figure 5.8), though the data are sparse. The data hint at latitudinal migration from southern and central Queensland in spring and summer (early-mid wet season) to central and northern Queensland in autumn and winter (early-mid dry season). Notably Flock Bronzewing Pigeons were consistently recorded from properties in the Gulf plains area only in winter.

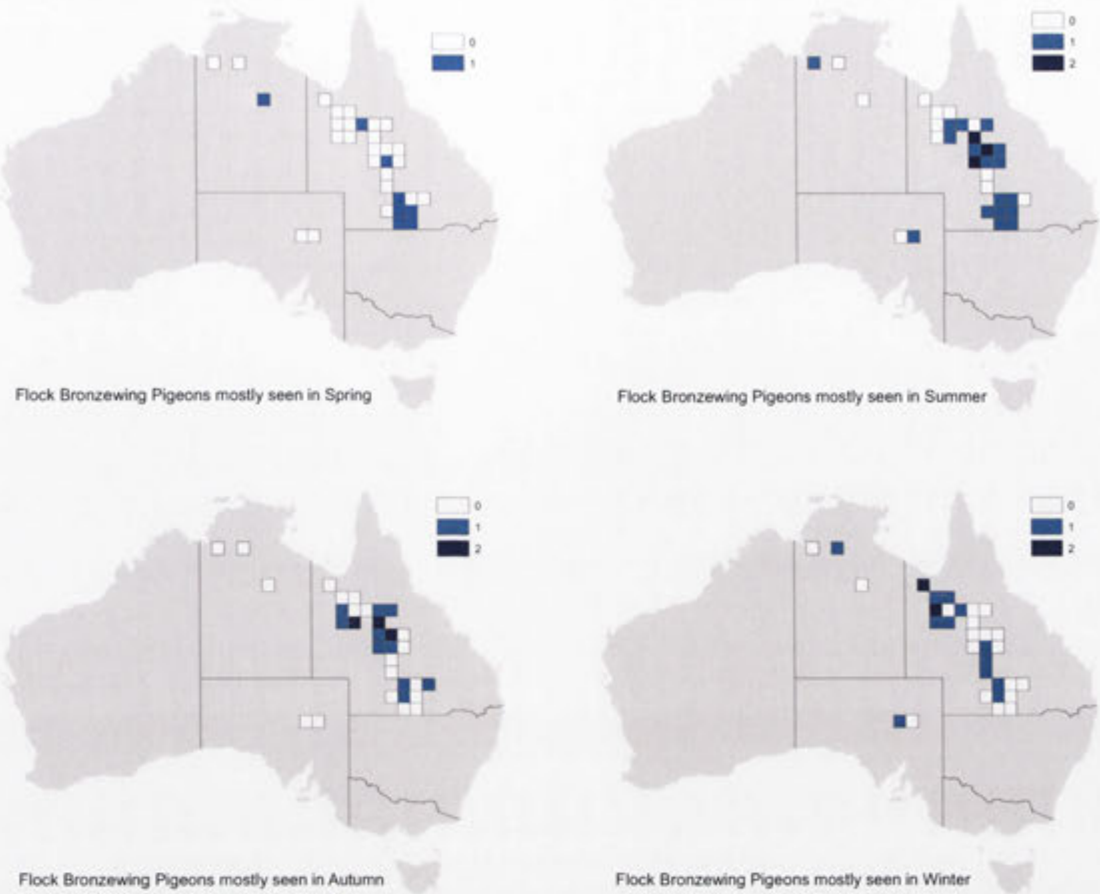


Figure 5.8 Degree cells with number of pastoral properties reporting Flock Bronzewing Pigeons in each of four seasons.

5.3.5 Inter-annual temporal patterns

Respondents identified marked inter-annual variation in abundance of Flock Bronzewing Pigeons on their properties (Figure 5.9). Data from the 2005 survey identified three episodes of above average abundance in the period 1970-2005: 1974-76, 1991-92 and 2000-01. These episodes correspond to periods of widespread above average rainfall and presumably sustained favourable conditions for pasture growth and seed production in each of four river catchments in western Queensland (Figure 5.10), though the details vary between catchments. In the Flinders River catchment there was above average rainfall in the years 1973/74, 1990/91 and 1996/97; in the Cooper Creek catchment there was above average rainfall in the years 1973/74, 1975/76, 1989/90, 1996/97 and 2000/01; in the Diamantina River catchment there was above average rainfall in the years 1973/74, 1975/76, 1989/90, 1996/97 and 2000/01; in the Georgina River catchment there was above average rainfall in the years 1973/74, 1975/76, 1990/91, 1996/97 and 2000/01. These episodes also correspond to periods in which floods were recorded in inland river systems. For Eyre Creek (part of the Georgina system) at Glengyle Station there were eight major flood events (ie >4m) since 1971: 1971, 1972, 1974, 1976, 1977, 1991, 1995, 1997 and 2001. The years 1955-56 were also noted as significant years by respondents in both surveys (Appendix 4). These four episodes (i.e. 1955-56, 1974-76, 1991-92 and 2000-01) also correspond to years in which the Southern Oscillation Index was strongly positive, though the relationship is less evident for 1991/92 (see Figure 4.4).

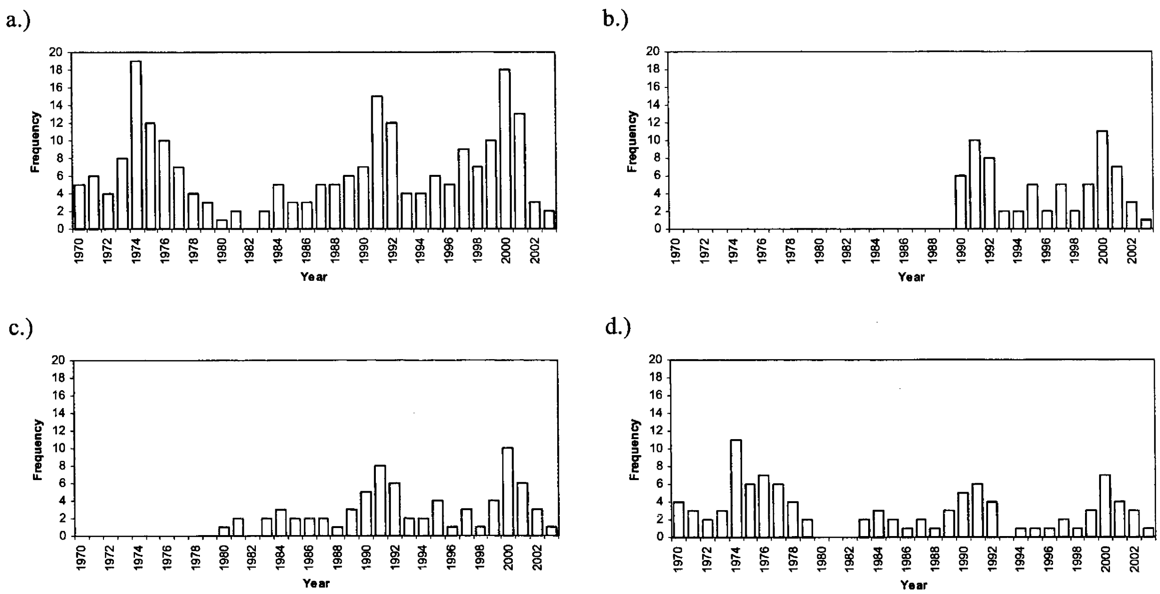


Figure 5.9 Frequency histograms of years reported as 'good for Flock Bronzewing Pigeons'.

a.) by all respondents to mail-out survey, b.) from 1990 by respondents to mail-out survey with at least 15 years in area, c.) from 1980 by respondents to mail-out survey with at least 25 years in area, d.) from 1970 by respondents to mail-out survey with at least 35 years in area.

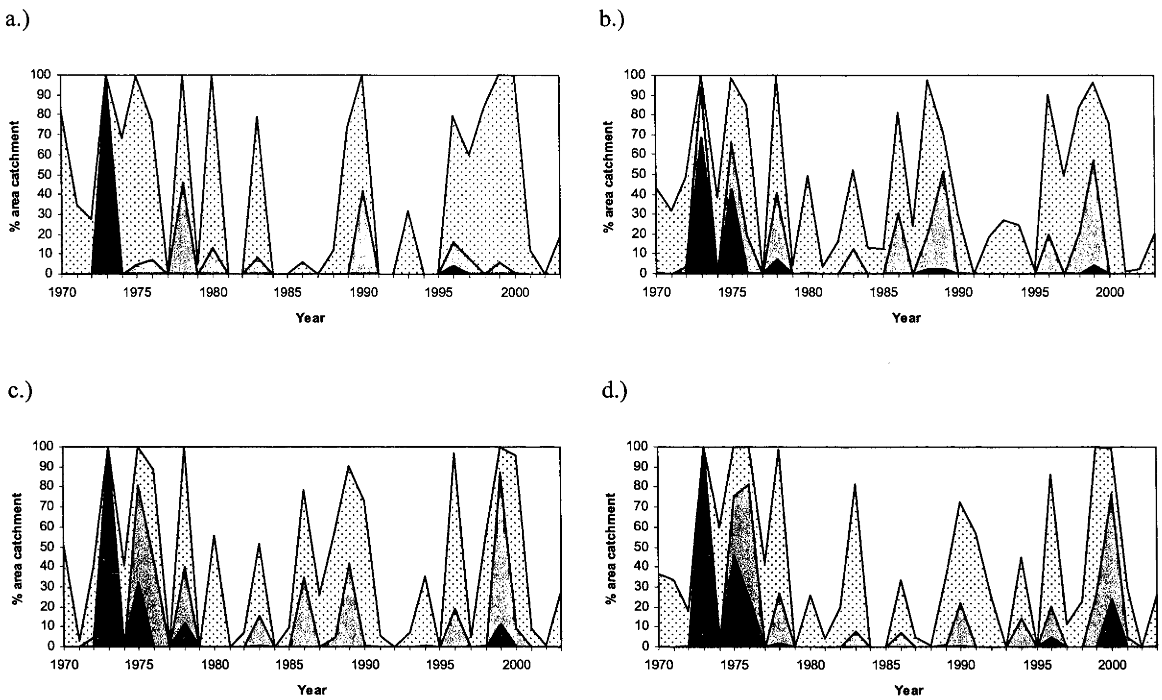


Figure 5.10 Percent area of catchment with above average rainfall in the period 1970/71 to 2005/06.

a.) Flinders River catchment, b.) Cooper creek catchment, c.) Diamantina River catchment, d.) Georgina River catchment. Stippled = 1-1.5 x average seasonal rainfall; light grey = 1.5-2 x average seasonal rainfall; dark grey >2 x average seasonal rainfall.

In each of the four periods identified as favourable for Flock Bronzewing Pigeons (i.e. 1955-56, 1974-76, 1991-92 and 2000-01, shown in Figure 5.11) sites are widespread across large areas of central inland Australia, though largely confined to the catchments of the Cooper, Diamantina, Flinders and Georgina river systems. This suggests that observations of increased abundance at these times is a response to phenomena which are operating on a similar broad scale.

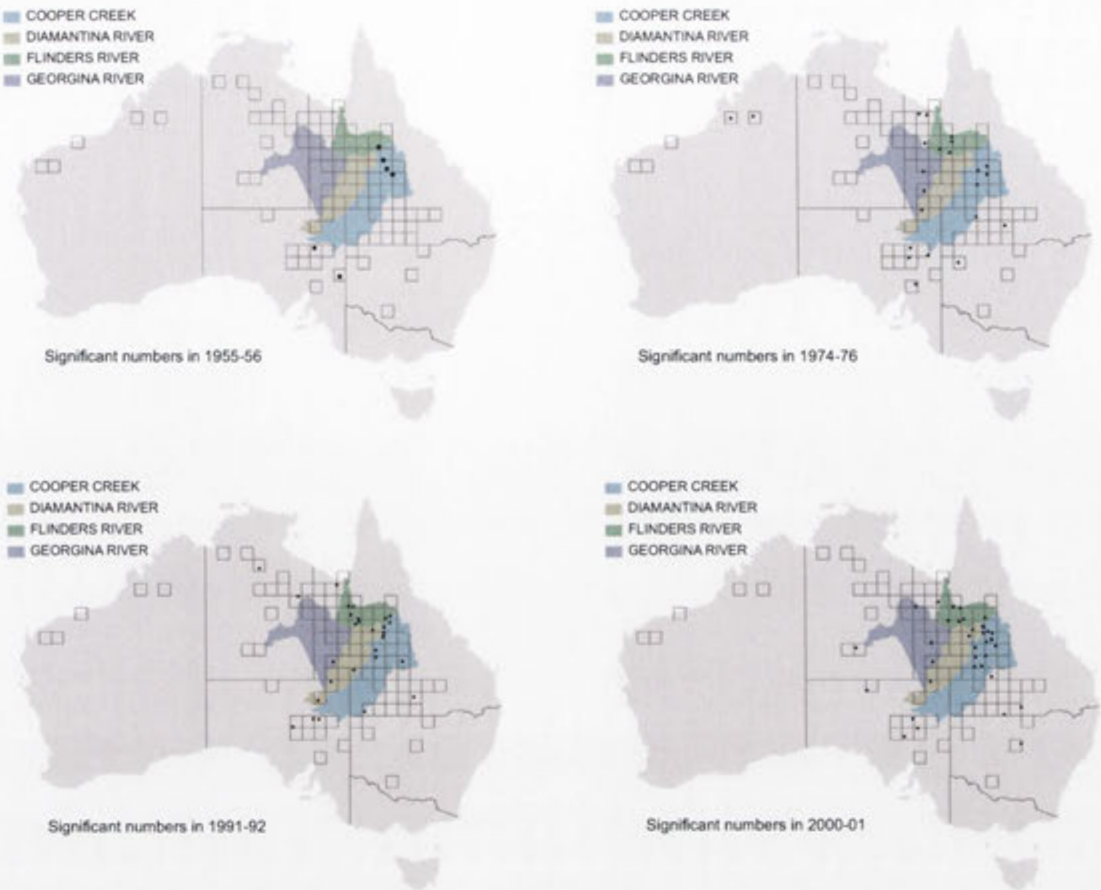


Figure 5.11 Distribution of properties reporting significant numbers of Flock Bronzewing Pigeons in each of four periods.

5.3.6 Breeding observations

Respondents reported that nests containing eggs were the most frequently identified signs of breeding of Flock Bronzewing Pigeons (Table 5.7). This result is somewhat anomalous given the difficulty of deliberately locating nesting birds, and the relative ease of observing aerial display flights associated with breeding activity. Whilst some observers were clearly familiar with this behaviour, it appears that many were not. Conversely, it may be that most observations of nests occur when mustering slow-moving stock, particularly sheep, in paddocks with nesting birds. Breeding observations occurred most frequently in the early dry season month of April (Figure 5.12). Breeding observations occurred throughout a large area, but were clustered in an area of the northern Mitchell grasslands in Queensland (Figure 5.13).

Table 5.7 Signs of breeding of Flock Bronzewing Pigeons reported by respondents.

Categories of breeding signs are not exclusive (n = 27).

Signs of breeding	Frequency
Nest with eggs	19
Chicks	11
Distraction display	10
Male display flight	9

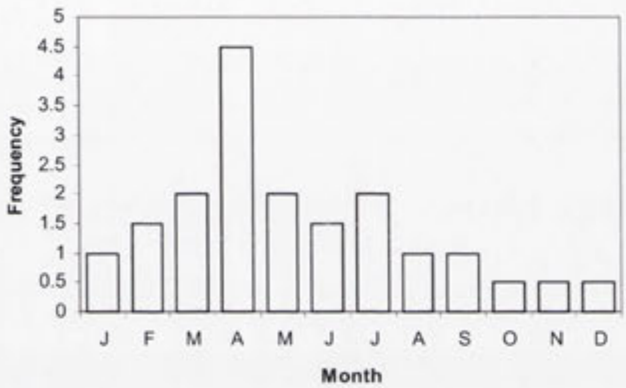


Figure 5.12 Frequency histogram of months in which signs of breeding were observed (n = 18).

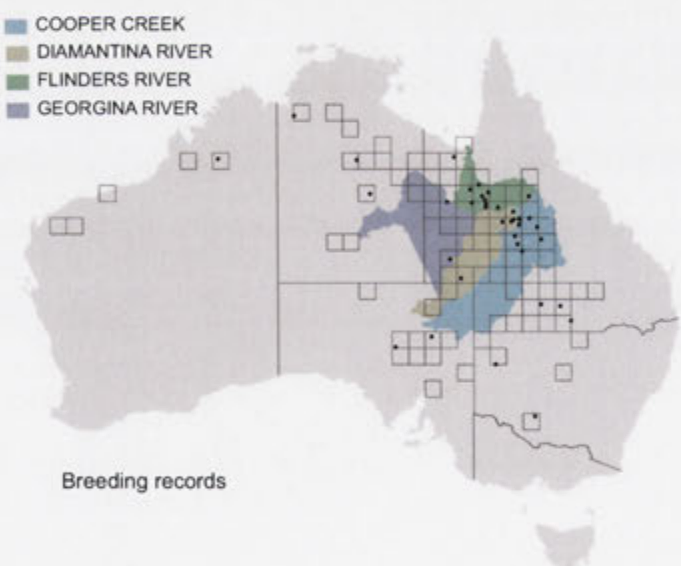


Figure 5.13 Distribution of properties on which signs of breeding were identified in either of both mail-out surveys.

5.3.7 Threatening processes

In the 2005 survey there were 114 responses to the question 'Have numbers of Flock Bronzewing Pigeons increased or decreased in region in your time?' Fifty-four respondents indicated that Flock Bronzewing Pigeons had decreased; 12 indicated an increase in numbers and the remainder (48) indicated no change (Table 5.8). Reasons listed for the decrease included drought or poor seasons (26 of 54), lack of seed due to drought or poor seasons (3 of 54), and introduced predators including feral cats and foxes (5 of 54). None specified overgrazing or loss of food resources due to grazing practices.

Table 5.8 Frequency of responses to the question on perception of current status.

Status	Frequency
Increased	12
Decreased	54
No change	48

5.3.8 Environmental correlates

Respondents identified the environmental factors 'good rainfall in your area' and 'grass seeding' as associated with good numbers and/or signs of breeding of Flock Bronzewing Pigeons. Only two respondents associated Flock Bronzewing Pigeons with 'fire' (Table 5.9).

Table 5.9 Percent frequency of environmental factors associated with occurrence of Flock Bronzewing Pigeons identified by survey respondents.

Categories of environmental factors were not mutually exclusive (n = 101).

Environmental factor	Frequency
Good rainfall in your area	82
Drought in your area	13
Drought elsewhere	16
Grass seeding	50
Fire	2
Receding floodwaters	9

5.3.9 Potential predators

Survey data suggest that the percent frequency of abundance classes of potential predators varies among land use types (Table 5.10), a result confirmed by binomial modelling (Tables 5.11 and 5.12). The occurrence of potential predators of ground-nesting birds varied with the type of pastoral land use: the probability of occurrence of foxes ranged from 0.53 for cattle properties, 0.85 for sheep and cattle properties, and 0.92 for sheep properties; the probability of occurrence of dingos/wild dogs ranged from 0.88 for cattle properties, 0.59 for sheep and cattle properties, and 0.34 for sheep properties (Figure 5.14). This suggests profound differences in predator pressure under different pastoral land use types. Survey data indicates that foxes were largely absent from most of the modelled range of Flock Bronzewing Pigeons (Figure 5.15), and that dingos/wild dogs were more prevalent in the northern portion of the modelled range (Figure 5.16).

Table 5.10 Percent frequency of abundance classes 'Absent', 'Present', 'Very abundant' for potential predators in each of three land use types.

	Abundance class for Fox *Vulpes vulpes*			
Land use	**% Absent**	**% Present**	**% Very abundant**	**Total**
Cattle	46.5	50.9	2.5	159
Sheep	7.6	82.3	10.1	79
Sheep & cattle	14.9	76.2	8.9	101
Total	95	223	21	339
	Abundance class for Dingo / wild dog *Canis lupus*			
Land use	**% Absent**	**% Present**	**% Very abundant**	**Total**
Cattle	11.7	54.9	33.3	162
Sheep	66.2	33.8	0.0	77
Sheep & cattle	40.6	51.5	7.9	101
Total	111	167	62	340

Table 5.11 Results of binomial modelling of relationship between occurrence of foxes and land use.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Land use	-173.49	4	355.11	0.00	1.0000	13.72
Null model	-201.09	2	406.21	51.10	0.0000	0.00

Table 5.12 Results of binomial modelling of relationship between occurrence of dingos/wild dogs and land use.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
Land use	-176.01	4	360.14	0.00	1.0000	18.04
Null model	-214.76	2	433.56	73.42	0.0000	0.00

a.) b.)

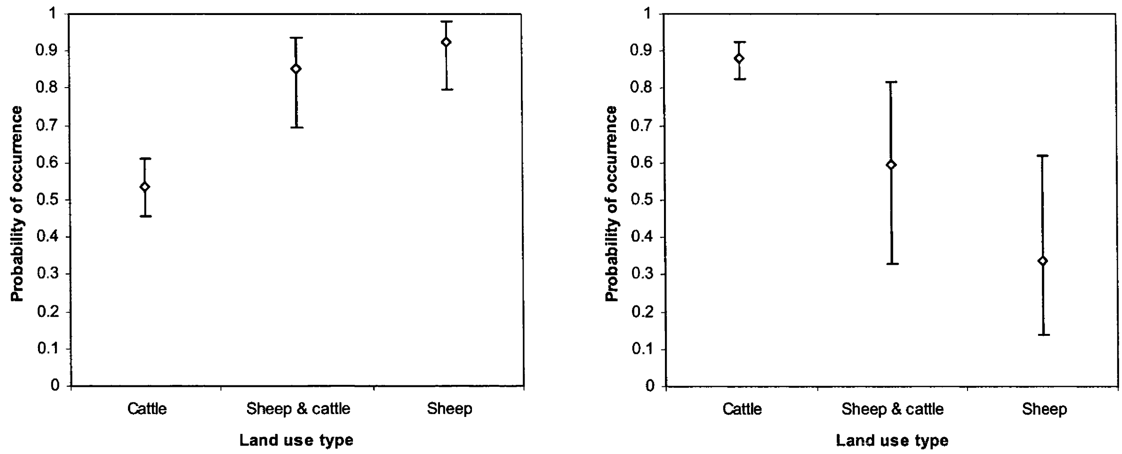


Figure 5.14 Probability of occurrence of a.) foxes and b.) dingos/wild dogs in three land use types.

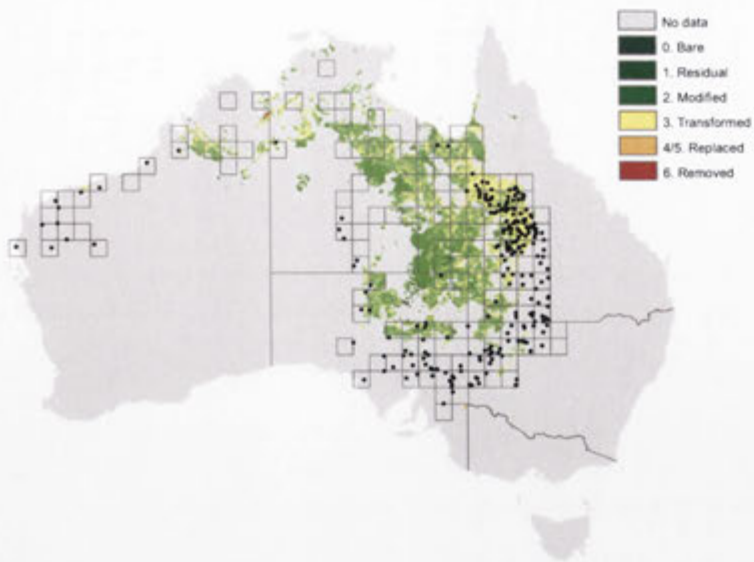


Figure 5.15 Distribution of respondents indicating that foxes were 'Present' or 'Very abundant' on their property.

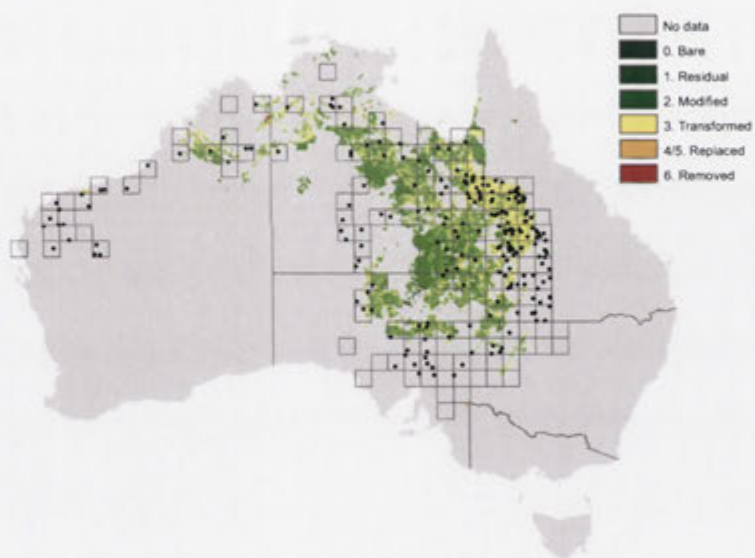


Figure 5.16 Distribution of respondents indicating that dingos/wild dogs were 'Present' or 'Very abundant' on their property.

5.3.10 Effect of grazing type

The distribution of the primary grazing types (Sheep, Sheep and cattle, and Cattle) are shown in Figures 5.17-5.19. Binomial modelling provided weak evidence of the effect of land use on the occurrence of Flock Bronzewing Pigeons. The preferred model did not include the variable Land use, and the model with the variable Land use alone accounted for only 3.6 % of the deviance. The modelling results are not consistent with the historical pattern of range contraction and the hypothesis that sheep grazing, or land management practices for sheep grazing, has contributed to the decline of the Flock Bronzewing Pigeon. The modelling provides only a weak test of the effect of land use on the patterns of occurrence of Flock Bronzewing Pigeons as it is based on recorded occurrence and not more robust measures such as frequency or duration of visits, or breeding success. Nevertheless, the data indicate that grasslands used for sheep production continue to provide habitat for this species.

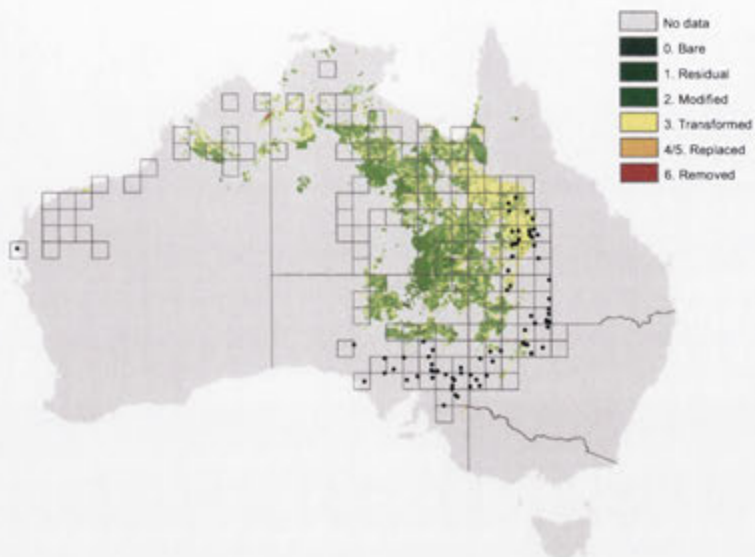


Figure 5.17 Distribution of respondents who listed sheep production as the main agricultural activity on their property.

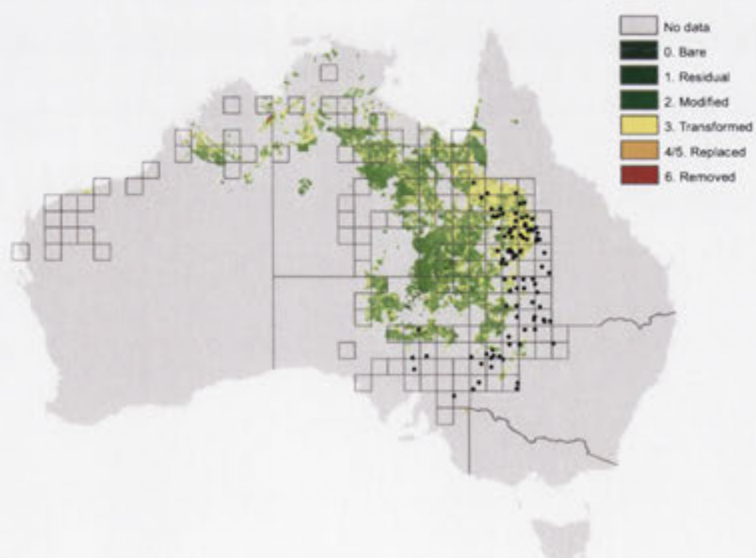


Figure 5.18 Distribution of respondents who listed sheep and cattle production as the main agricultural activity on their property.

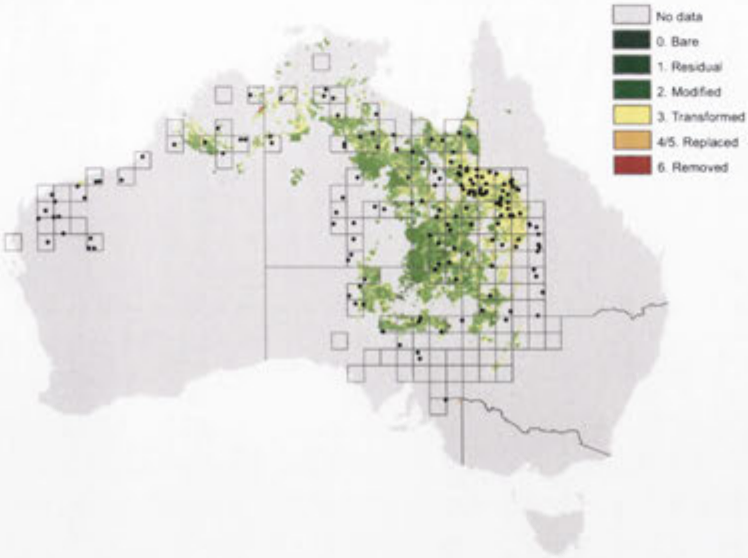


Figure 5.19 Distribution of respondents who listed cattle production as the main agricultural activity on their property.

5.3.11 Comments and observations from respondents

Mail-out surveys provided reports of either 'huge flocks' or 'thousands' of Flock Bronzewing Pigeons from landholders in 14 one-degree cells (13 in Queensland, and one in South Australia) (Figure 5.20). These mostly occurred across central western Queensland within the latitudinal band 18-21°S, and most refer to events occurring 30-40 years previously. At least three refer to large flocks in early 1970s, in one case flocks estimated to contain hundreds of thousands of birds. For three of these reports large flocks were associated with recent mid-winter rainfall which was considered to have caused an exodus from elsewhere, presumably Channel Country properties.

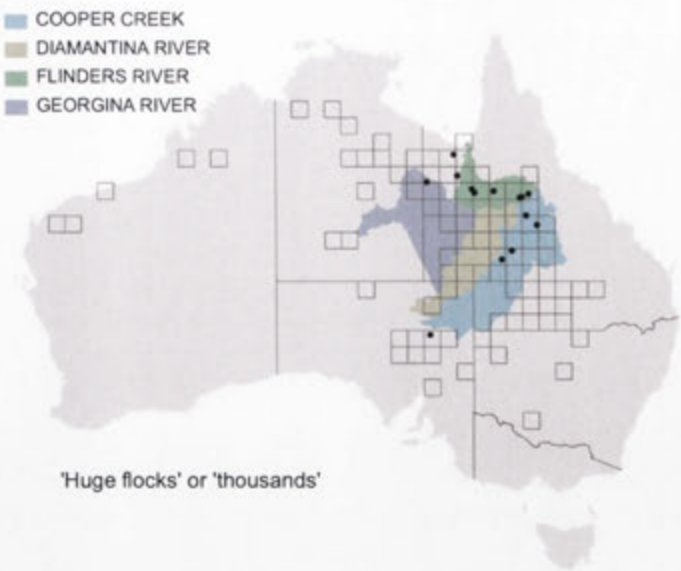


Figure 5.20 Distribution of respondents reporting 'huge flocks' or 'thousands' in either of both mail-out surveys.

There is ample evidence from the comments listed in appendices (see Appendix 4) that property owners understand the fundamental biological requirements of the species. For example, there were six explicit comments that connected the presence of Flock Bronzewing Pigeons to the amount of seed available on the ground.

5.4 DISCUSSION

The mail-out survey was successful in eliciting information on aspects of the ecology of the Flock Bronzewing Pigeon. The mail-out survey yielded a response rate of 14.9%; this is comparable to the response rate of 15.1% in an earlier survey on the Australian Bustard (Ziembicki and Woinarski 2007). Whilst it should be acknowledged that there is inevitable variability in experience, residency and ecological knowledge of respondents, the advantages of inexpensive data collection over extensive parts of the continent, and the potential of a long-term temporal perspective, outweigh the issue of lack of control on data quality. The survey demonstrates that rangeland residents can make a significant contribution to understanding ecological phenomena. The principal shortcoming of this survey arises from the spatial bias in the distribution of respondents and the fact that key regions for the species, such as the Barkly Tableland and the Channel Country, were not well represented largely because of the relatively few properties in these regions. The concentration of reports of Flock Bronzewing Pigeons in the Mitchell Grass Downs in central Queensland (Figure 5.5) constrasts with results from analysis of faunal database records.

The survey provided evidence that Flock Bronzewing Pigeons occur episodically within large areas of their predicted range: more than a third of all respondents (36%) indicated that Flock Bronzewing Pigeons had occurred on their property; with 71.2% of these indicating that Flock Bronzewing Pigeons had been observed in the previous 12 month period. However, for many respondents, occurrences were rare, infrequent events associated with above average rainfall.

The connection between pulses of productivity due to rainfall and population responses of Flock Bronzewing Pigeons was noted by early observers (e.g. Carter 1902), and was recognised by many survey respondents. Episodes of high abundance of Flock Bronzewing Pigeons in the years 1955-56, 1974-76, 1991-92 and 2000-01 were associated with ENSO-related climatic variability (McKeon *et al.* 2004). Resource pulses associated with this phenomenon have a profound influence on vegetation structure, seed bank replenishment and vertebrate populations (Lima *et al.* 1999, Letnic *et al.* 2005, Holmgren *et al.* 2006). It is not clear whether respondents were recalling exact years of high Flock Bronzewing Pigeon abundance *per se*, or linking known and widely recognised favourable sequences of years with high Flock Bronzewing Pigeon abundance. In any case, the data provide evidence that populations undergo marked fluctuations on a decadal time-frame, and that they are linked to widespread rainfall events or the aftermath, e.g. flooding of inland rivers, of significant rainfall events.

Data from both surveys provide some evidence of regular annual latitudinal movements with birds being noted by respondents in central southern Queensland in summer months and in northern areas in mid-dry (winter) months, though it is possible that this supposition is simply an artefact of recent rainfall history. Historical records of occurrence in northern New South Wales (summarised in McAllan (1996)) do not contradict the hypothesis of seasonal latitudinal migration but as Frith (1982) notes, ornithological observations commenced simultaneously with the commencement of sheep grazing and the disappearance of Flock Bronzewing Pigeon populations in all but north-western regions of New South Wales, and there is a very limited basis to determine their original status and patterns of occurrence. North (1913) presented observations from correspondents who noted:

> In the year 1864, when this part of the country [Mossgiel district] was first occupied, Phaps histrionica was found on these wide plains in countless multitudes. They made their appearance in July or the beginning of August, and bred during the months of October and November all over the plains (North 1913).

> The Harlequin Bronze-wing usually appears in this district [Nyngan region] immediately upon the break up of drought, when heavy rains make the 'wild sago' grow, which is the first herbage to make its appearance. Then they

> come in great numbers, and stay several months, breeding in the meanwhile. They lay in thousands all over the plain . . . (North 1913).

It seems that in areas with increasing dominance of winter rainfall, arrival and breeding coincided with seedfall after growth of herbage in spring months.

Respondents identified the early dry season months of April as a peak month for signs of breeding activity, a result consistent with other observations in the northern sub-tropics (Berney 1906). At this time the northern monsoon has subsided and seed availability increases as herbage senesces.

The data provide no evidence that type of land use (Sheep, Sheep and cattle, Cattle) influenced the probability of occurrence of Flock Bronzewing Pigeons, though the test is far from robust. The historical record suggests that Flock Bronzewing Pigeons ceased to be residents or regular visitors to the southern parts of their former range by the late 1800s. This pattern mirrored the faunal collapse in western New South Wales attributed to loss of landscape productivity by sheep grazing (Lunney 2001). Impacts of pastoralism on fauna in the Australian rangelands vary geographically, with impacts greater in the sheep grazing lands than in the cattle grazing lands, purportedly due to the greater density of watering points and higher densities of herbivores and foxes (Letnic 2007). There are interactions between grazing type, predator type, and climatic variability which confound interpretation of ecological processes. The distributions of foxes and dingos are to some extent inversely related (this study, Letnic 2007), due in part to active suppression of dingos in sheep grazing lands. The removal of the dingo has been implicated in the collapse of populations of marsupial prey species by ecological release of medium-sized predators including the fox and feral cat (Johnson *et al.* 2006). This mechanism is implicated in local extinctions of birds in North America (Crooks and Soule 1999), though a review of studies on the effect of predator control on bird populations revealed widely differing results (Cote and Sutherland 1997). Garnett and Crowley (2000) assert that the area of decline of Flock Bronzewing Pigeons corresponds to the distribution of foxes, and that they persisted in areas of heavy stocking in the absence of foxes in New South Wales until the end of the 19th century: an assertion not entirely supported by the sparse historical evidence (McAllan 1996). This study suggests that Flock Bronzewing Pigeons continue to occasionally occur in the presence of foxes on sheep-grazing lands, at least in northern Mitchell grasslands, and at times to nest successfully. I conclude that the role of northern sheep-grazing lands as habitat for Flock Bronzewing Pigeons not be ignored by conservation managers, and that far more knowledge is required of resource and habitat use on both sheep-grazing and cattle-grazing lands.

5.5 SUMMARY OF FINDINGS AND CONCLUSIONS

A mail-out survey of rangeland users was conducted in late 2005 to provide data on the occurrence of Flock Bronzewing Pigeons on individual pastoral properties throughout their range. Over four hundred (406 of 2,733 distributed, 14.9%) survey forms were returned, with the majority from a region with a relatively high density of pastoral properties in central Queensland. More than a third of all respondents (36%) indicated that Flock Bronzewing Pigeons had occurred on their property; 71.2% of these indicated that Flock Bronzewing Pigeons had been observed in the previous 12 month period; but for many respondents occurrences of Flock Bronzewing Pigeons were rare infrequent events associated with good rainfall and a substantial vegetation reponse.

There is some evidence of latitudinal migration in Queensland: Flock Bronzewing Pigeons tended to be summer wet season visitors in the southern portion, and winter dry season visitors in the northern portion. Reports of breeding signs peaked in the early dry season month of April.

Respondents perceived at least four episodes of high Flock Bronzewing Pigeon abundance in the period from 1950 including the years 1955-56, 1974-76, 1991-92 and 2000-01, corresponding to widespread above-average rainfall, flooding in inland catchments and positive Southern Oscillation Index values.

The data provided no evidence that the type of pastoral land use (Sheep, Sheep and cattle, or Cattle) influenced the probability of occurrence of Flock Bronzewing Pigeons, though the test based on recorded occurrence is relatively weak and the result is not consistent with the historical pattern of range contraction. The occurrence of potential predators of ground-nesting birds varied with the type of pastoral land use: the probability of occurrence of foxes ranged from 0.53 for cattle properties, 0.85 for sheep and cattle properties, and 0.92 for sheep properties; the probability of occurrence of dingos/wild dogs ranged from 0.88 for cattle properties, 0.59 for sheep and cattle properties, and 0.34 for sheep properties. This suggests profound differences in predator pressure under different pastoral land use types.

Chapter 6: PATTERNS OF DISTRIBUTION AND ABUNDANCE OF FLOCK BRONZEWING PIGEONS. RESULTS FROM A CONTINUOUS COMMUNITY-BASED SURVEY, 2006-2007

6.1 INTRODUCTION

Many organisms in northern Australia exploit asynchronous resources across a spatially dispersed resource archipelago, e.g. waterbirds inhabiting seasonal wetlands (Whitehead *et al.* 1992), frugivorous birds inhabiting rainforest patches (Price 2004), nectarivorous bats and honeyeaters inhabiting savanna woodlands (Palmer and Woinarski 1999, Woinarski *et al.* 1992, Woinarski *et al.* 2000) and granivorous finches inhabiting grassy savanna woodlands (Dostine *et al.* 2001). The conservation and management of such mobile species which potentially interact with habitat and resources across large spatial scales present special difficulties for researchers and managers (Woinarski *et al.* 1992, Recher 2007). Knowledge of the nature of movements is fundamental to understanding their ecology and thus their conservation (Soule *et al.* 1984).

In a review (then) of recently acquired records of Flock Bronzewing Pigeons from central Australia, Parker (1969) mused that they periodically pulse from core habitat:

> Presumably in good years this pigeon spills off the Barkly to occur in small numbers over most of the Territory (Parker 1969).

Frith (1982) concurred with this model.

> . . . most of the evidence . . . suggests that there were districts with good Mitchell grass plains, particularly in the north, from about Camooweal to the Stuart Highway [i.e. Barkly Tableland in N.T.], where the birds were always found in large numbers but many of the occurrences reported elsewhere were short lived and the result of nomadic movements after exceptionally good seasons (Frith 1982).

The model implies that Flock Bronzewing Pigeons are permanent residents within core habitat; that occurrences elsewhere derive from emigration from core habitat; that core habitat largely distinguishes breeding from non-breeding habitat; that dispersive movements from core habitat are uni-directional; and that peripheral populations are ephemeral. However, the extent to which this is true is unclear as there has been no quantitative analysis of distributional patterns that might lead to the conclusion that northern Mitchell grass plains constitute core refuge habitat for this species. An alternative model might be termed 'serial-nomadism'; in which the population flux is not centred on core habitat, but leads to large-scale spatial reconfiguration to exploit ephemeral resources which occur in response to variable and erratic rainfall. Invasions are short-lived and persist until resource depletion, usually by seed germination after summer rainfall. Distinguishing between these two scenarios will require long-term information on the movement patterns of individual birds (the 'life-time track' Roshier and Reid 2003). Such information is currently unavailable for this species, and surrogate data from community-based surveys were sought to attempt to address this question.

Community-based surveys have provided the means to document temporal and spatial variation in abundance and elucidate seasonal movement patterns of Australian land birds (e.g. Clarke *et al.* 1999, Griffioen and Clarke 2002). Analyses such as the study of Griffioen and Clarke (2002) are useful when there is sufficient data that are collected at the same temporal scale as movement behaviours: analyses which pool data at inappropriate temporal scales may mask the idiosyncratic nature of responses (Ziembicki and Woinarski 2007). Within much of the range of the Flock Bronzewing Pigeon human population density is low and the pool of potential volunteer observers is small. There are precedents for eliciting the assistance of rangeland residents in ecological studies (Carstairs 1974, Wyndham 1983, Barrett 2000, Ziembicki and Woinarski 2007). Wyndham (1983) used monthly questionnaire surveys to obtain information on movement patterns and breeding seasons of the Budgerigar and noted that the methods used may be applicable to other terrestrial birds of inland Australia.

The study reported here seeks to examine spatial and temporal patterns of abundance of the Flock Bronzewing Pigeon using data on relative abundance obtained from an observer network, and to interpret distributional patterns using satellite-derived information on broad-scale patterns of plant productivity. Specifically, this chapter addresses the following questions:

(1) Is there evidence that the northern Mitchell grass plains constitute 'core' habitat for this species?
(2) Is there evidence of seasonally–based movement behaviour patterns for this species?
(3) Are there spatial patterns in relative abundance?
(4) What are the correlates of spatial patterns?
(5) Is it possible to infer movement patterns?

(6) Is there evidence that supports or refutes either the 'core habitat' or 'serial-nomad' model of movement?

6.2 METHODS

6.2.1 Patterns of plant productivity

Monthly data on gross primary productivity (GPP) of the raingreen component of vegetation were calculated from fPAR data provided by S. Berry of ANU FSES using methods described by Berry *et al.* (2007). Data were derived from NDVI (Normalized Difference Vegetation Index) imagery captured by sensors borne on the MODIS satellite. The NDVI is defined as NDVI = (NIR-VIS)/(NIR+VIS) where NIR and VIS are the near infra-red and visible reflectance. NDVI is a robust estimator of green vegetation cover at regional and continental scales (Roderick *et al.* 1999). NDVI data were converted to total fPAR (fraction of photosynthetically active radiation) and partitioned into evergreen and raingreen components using methods summarised in Roderick *et al.* (1999) and Berry and Roderick (2002). The distribution of raingreen fPAR corresponds to the distribution of seasonal green grasslands and herbfields, particularly on fine-textured cracking clay soils (Berry and Roderick 2002).

IDRISI grid files of total and evergreen fPAR were converted to ESRI grid format in ArcMap, and resampled to a cell size of 0.0025 decimal degrees with a common grid extent and datum (WGS 1984). Monthly raingreen fPAR data were converted to raingreen GPP using calibrations provided by S. Berry and based on methods presented in Roderick *et al.* (2001). Mean monthly GPP data for four geographic regions defined by blocks of one degree cells (Barkly Tableland in the Northern Territory, northern Mitchell grass region of Queensland, southern Mitchell grass region of Queensland, and Channel Country of south-west Queensland) were derived using ArcGIS (ESRI 2004) from 1,000 randomly selected points per block. From these data the average of the top 100 values were calculated. Percent frequency of GPP data classes are presented as frequency histograms.

6.2.2 Survey of Flock Bronzewing Pigeon abundance

A mail-out survey to pastoral landholders in northern Australia in late 2005 was used to identify volunteers willing to be contacted on a regular basis to provide information on the local abundance of the Flock Bronzewing Pigeon. Observers were initially contacted by mail and asked to nominate the preferred method of subsequent contact i.e. telephone, letter, fax or email. Observers were contacted over 18 consecutive months from January 2006 to June 2007 and asked to assess Flock Bronzewing Pigeon numbers on their property according to the scale described in Table 6.1.

Table 6.1 Abundance ranks used for survey of Flock Bronzewing Pigeon numbers on pastoral properties.

Abundance rank	Description
0	None
1	Between 1 – 10
2	Between 10 - 100
3	Between 100 – 1,000
4	Between 1,000 – 10,000
5	More than 10,000
6	Can't tell, I was away or didn't get out

Not all observers were contacted on each occasion; some could not be contacted due to absence from their property, others occasionally declined to respond to email requests. An effort was made to successfully contact at least 50 observers per month; this was achieved on all months except for the wet season months of December 2006 and January 2007 (Table 6.2). Observers were contacted at the end of each month. Telephone calls were made in the evening usually after 19:00 hours local time.

Three summary metrics were devised to examine the spatial distribution of survey data. These include (i) maximum abundance ranks from all surveys within a degree cell of latitude and longitude; (ii) relative frequency i.e. number of months with records of Flock Bronzewing Pigeon presence divided by the number of months with survey data for each degree cell ($N_{present}$/ N_{total}, where $N_{total} \geq 5$); and (iii) relative importance i.e. sum of monthly maximum abundance ranks divided by number of months with survey data for each degree cell (Σ_{ranks}./ N_{total}, where $N_{total} \geq 5$).

The number of contributing correspondents by one-degree cells of latitude and longitude are shown in Figure 6.4. Data were analysed within four blocks of one-degree cells as noted above. The number of survey respondents varied between blocks as follows: Barkly Tableland (n=5), northern Mitchell grass plains (n=16), southern Mitchell grass plains (n=36), and Channel Country (n=8). Survey results were tallied and summarised by state. For all sites combined and for each block, monthly survey totals per rank are presented in tabular form; data expressed as percent frequency per rank (excluding category 6) are presented in frequency histograms.

6.2.3 Relationship between pigeon abundance and plant productivity

For each of four survey blocks, cross-correlation analysis was used to examine the relationship between time-series data of maximum rank per month, GPP and deviation from mean monthly GPP. Cross-correlation analysis used methods of Croke (2005), and a software program written in Fortran language and provided by B. Croke of ANU FSES.

The relationship between distribution data and patterns of rainfall, GPP and deviation from mean monthly GPP is shown graphically. Three sets of maps are presented showing: (i) survey data for January 2006 and GPP data for August 2005; (ii) survey data for October 2006 and GPP data for May 2006; and (iii) survey data for June 2007 and GPP data for February 2007.

6.2.4 Caveats and interpretation

As noted for the analysis of the mail-out survey data, there are caveats attached to these analyses. There is unavoidable variation between observers in their ecological knowledge, reliability and length of residency; there is also unavoidable variation in the type and scale of their daily operations and thus the areas in which Flock Bronzewing Pigeons may be seen, and consequently their capacity to estimate local abundance. Throughout the range of the species there is considerable variation in the size of pastoral enterprises, and thus the density of potential observers. The Barkly Tableland in the Northern Territory is dominated by large, company owned, cattle stations; in contrast, the sheep lands of central Queensland are dominated by small properties. Consequently there is an unavoidable bias in the density of reporters and data points.

6.3 RESULTS

6.3.1 Patterns of gross primary productivity of ephemeral vegetation

Plant growth on the Barkly Tableland is highly seasonal (Figures 6.1a and 6.2a), linked to the summer monsoon rainfall system. Data from the entire available record (May 2000-June 2007) indicate that there is substantial inter-annual variability in the timing, duration and extent of plant growth pulses. These are expected to have substantial effects on cattle production and the population dynamics of wildlife (Taylor and Tulloch 1985). In particular there have been two rainfall-years with above average pasture growth and protracted growing seasons i.e. 2000/01 and 2005/06. The year 2005/06 was preceded by a below average year for pasture growth.

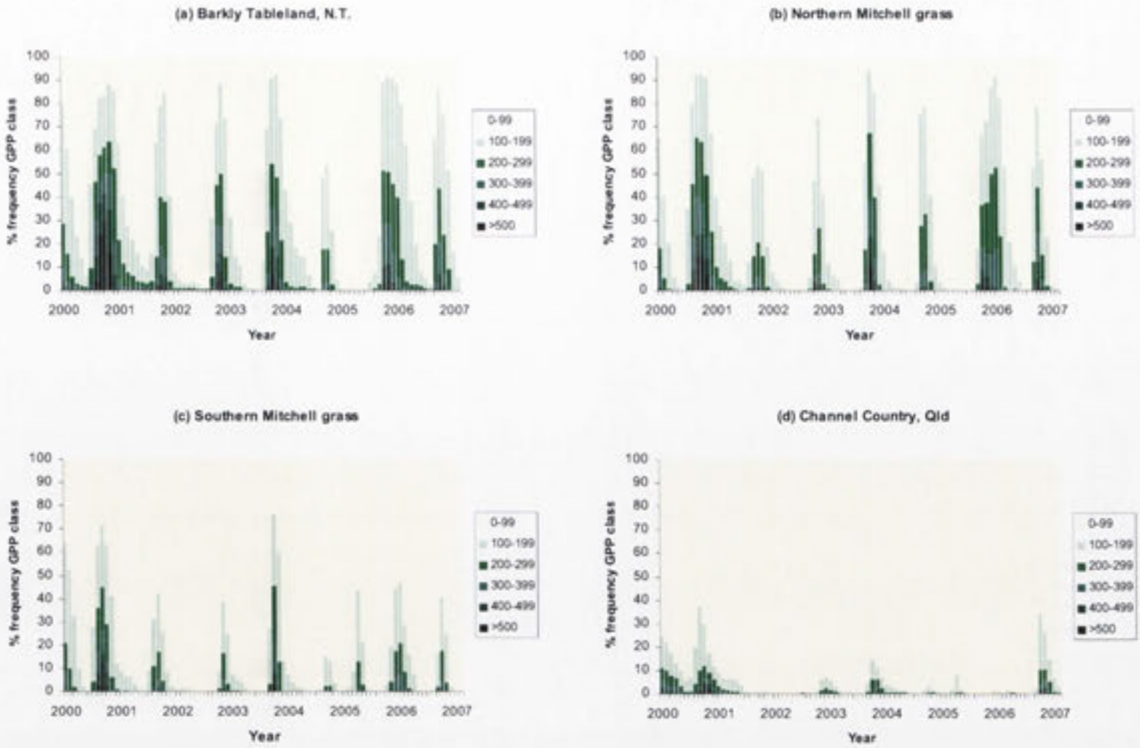


Figure 6.1 Percent frequency of classes of GPP values derived from intersection of time-series of GPP imagery and 1,000 randomly selected points in each of four survey blocks, over the period 2000-2007.

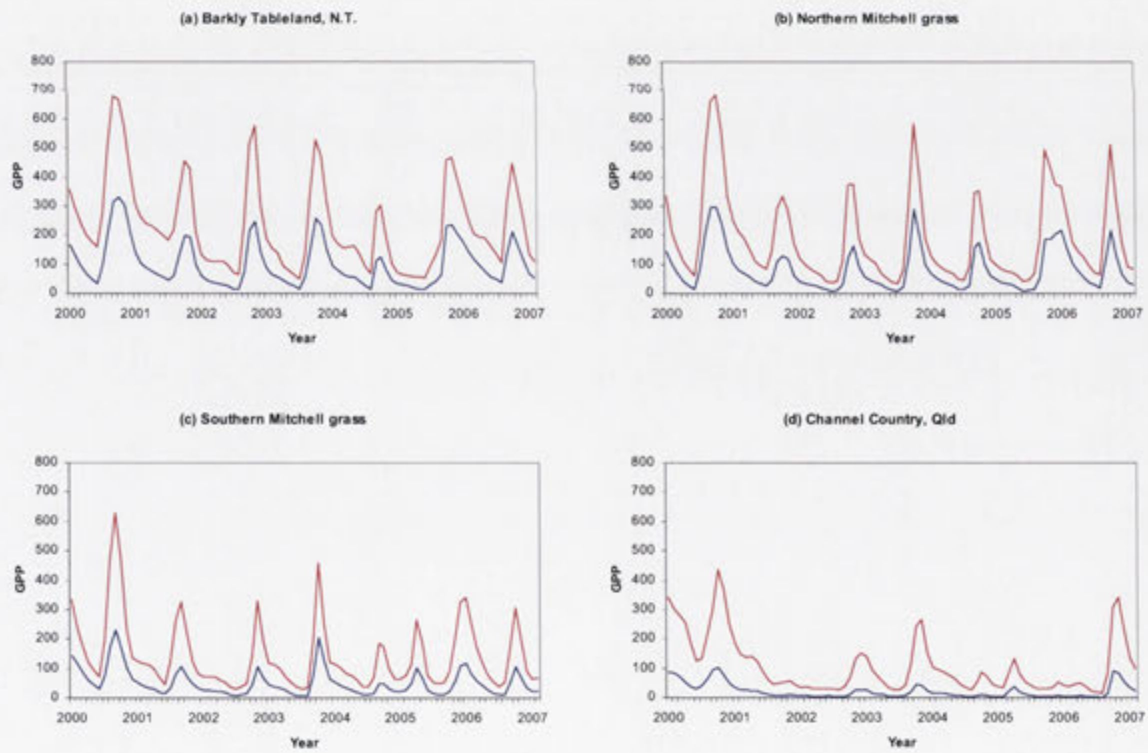


Figure 6.2 Monthly GPP calculated from intersection of time-series of GPP imagery and 1,000 randomly selected points in each of four survey blocks.

Blue line = overall mean, red line = mean of maximum 10% per month.

Patterns of plant growth in the northern Mitchell grass survey block are similar to those on the Barkly Tableland (Figures 6.1b and 6.2b), with highly seasonal predictable pulses of plant growth and inter-annual variability in timing, duration and extent of pulses. Similarly, the rainfall-years 2000/01 and 2005/06 are above average, and 2005/06 is preceded by a year of limited plant growth.

In the southern Mitchell grass survey block plant growth is seasonal and occurred at a reduced spatial extent relative to Barkly Tableland and northern Mitchell grass blocks (Figures 6.1c and 6.2c). The rainfall-year of 2005/06 was preceded by an extremely low summer growth period, and unseasonal winter growth following substantial rainfall in June 2005.

Plant growth in the Channel Country survey block is far less seasonal (Figures 6.1d and 6.2d) and spatially confined to floodplains associated with major drainage systems (Figure 6.3). Plant growth pulses of 2000/01 and 2006/07 are associated with flooding episodes in the Georgina River system.

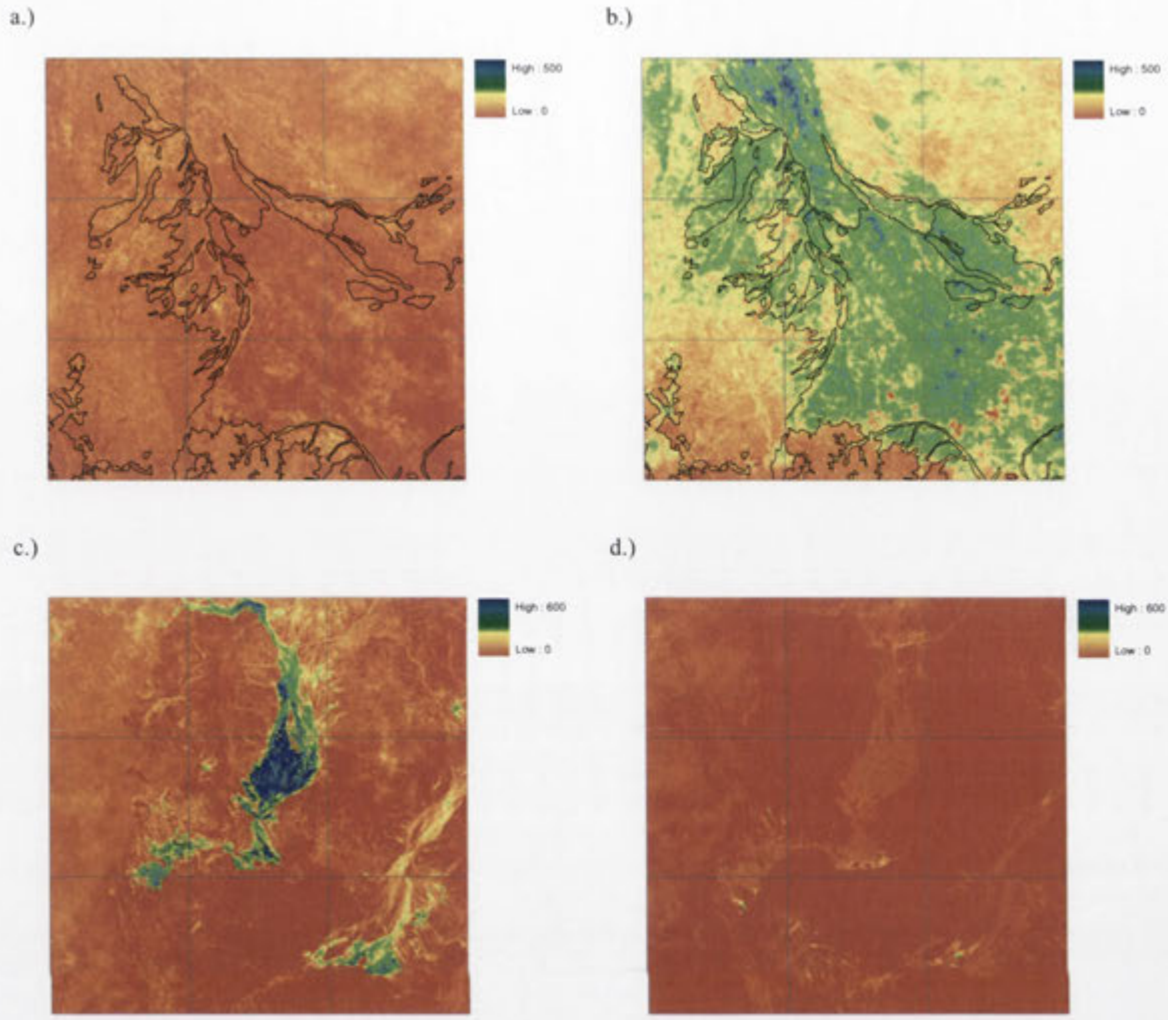


Figure 6.3 Inter-annual variation in GPP.

a.) GPP data from northern Mitchell grass survey block May 2005 showing boundaries of Mitchell grass communities, b.) GPP data from northern Mitchell grass survey block May 2006 showing boundaries of Mitchell grass communities, c.) GPP data from Channel Country survey block March 2001, d.) GPP data from Channel Country survey block March 2002.

6.3.2 Survey of Flock Bronzewing Pigeon relative abundance

Over the period of the survey there were 1,154 individual monthly reports of Flock Bronzewing Pigeon abundance from 118 observers distributed within 62 one-degree cells of latitude and longitude (Table 6.2). These were distributed across five states and overlapped the majority of the mapped area of Mitchell grasslands (Figure 6.4), though the majority (79%) of reports were from the state of Queensland. The proportion of total reports indicating that Flock Bronzewing Pigeons were present varied between states. For example, of 109 monthly reports from South Australia, Flock Bronzewing Pigeons were reported as present on only one occasion (0.9%); but were present on 318 of 912 occasions in Queensland (34.9%) (Table 6.3).

Table 6.2 Frequency of abundance ranks of Flock Bronzewing Pigeons by month from January 2006-June 2007.

Rank	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	Total
0	47	48	49	44	44	35	57	46	41	42	37	30	35	42	41	44	47	46	775
1	15	6	11	9	9	10	8	2	7	4	5	5	3	19	16	10	15	16	170
2	11	11	2	7	3	7	8	8	4	4	4	1	3	11	13	7	5	2	111
3	11	3	1	1	3	3	4	2	4	4	3	2	2	3	6	7	3	7	69
4			1			2	1	3	3	3	3	2		2	1	1	2	2	26
5											1	2							3
Sub-total	84	68	64	61	59	57	78	61	59	57	53	42	43	77	77	69	72	73	1,154
6	8	16	11	2				1		2		1	2	1	1	1	1	2	49
Total	92	84	75	63	59	57	78	62	59	59	53	43	45	78	78	70	73	75	1,203

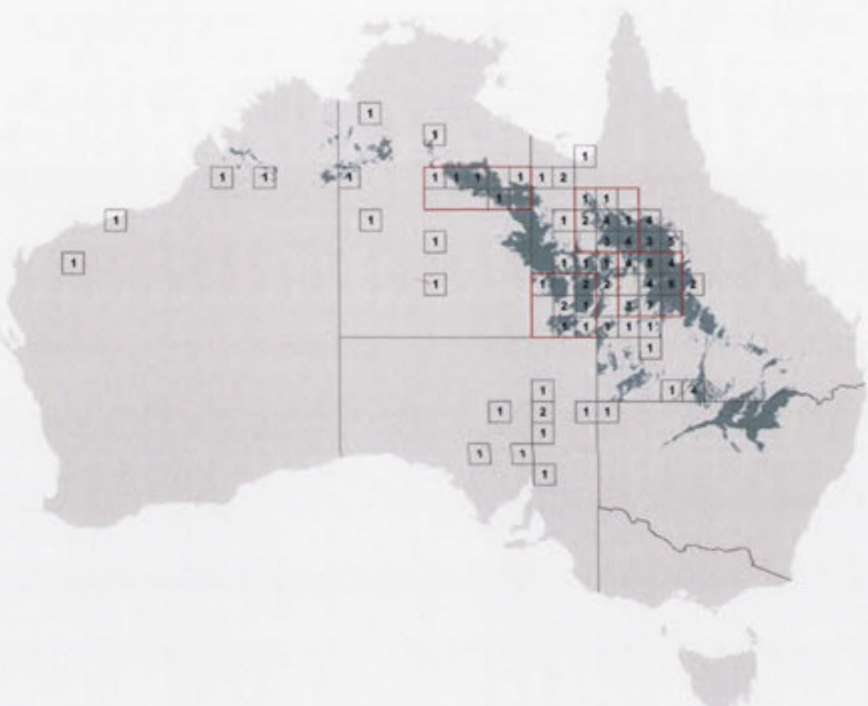


Figure 6.4 Map showing extent of survey area and number of contributing respondents for monthly survey data per degree cell of latitude and longitude.

Location of four survey blocks and mapped distribution of Mitchell grass communities also shown.

Table 6.3 Summary of distribution of survey responses by state.

State	# reports	% # reports	#observers	% # observers	# deg cells	% # deg cells	# present	% # present
WA	41	3.6	4	3.4	4	6.5	4	9.8
NT	80	6.9	11	9.3	11	17.7	54	68
Qld	912	79.0	93	78.8	38	61.3	318	34.9
SA	109	9.4	9	7.6	8	12.9	1	0.9
NSW	12	1.0	1	0.8	1	1.6	2	16.7
Total	1,154		118		62		379	32.8

On most occasions Flock Bronzewing Pigeons were absent from most sites: across the entire survey period absences were reported at 775 of a total of 1,154 (67%) sites. Throughout the dry season months of 2006 there was a steady increase in the proportion of sites reporting abundance ranks of 3, 4 or 5, but this increase was not matched by an increase in proportion of occupied sites overall. There were no reports of large aggregations in January 2007, presumably due partly to dispersal triggered by wet season rainfall. In the late wet season and early dry season months of 2007, the proportion of occupied sites increased, presumably following dispersal from favoured areas of the previous late dry season (Figure 6.5).

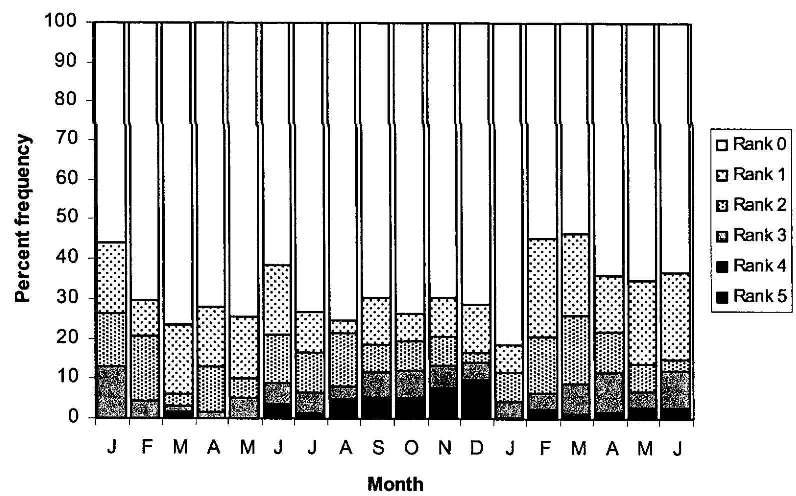


Figure 6.5 Percent frequency of Flock Bronzewing Pigeon abundance ranks per month during survey period January 2006-June 2007.

The distributions of the three metrics derived from survey data (maximum rank, relative frequency, relative importance) have a northern bias (Figure 6.6) and suggest that the Barkly Tableland and similar habitat on Mitchell grass downs in northern central Queensland, and the Channel County in far south-west Queensland constitute the core parts of the range of the Flock Bronzewing Pigeon. A notable outlier is the Tanami region in the western Northern Territory. Throughout 2006 there were regular sightings of small groups of Flock Bronzewing Pigeons, usually arriving to drink at the edge of palaeo-channels which had flooded after a heavy rainfall event in early 2006. In November 2006 a total of between 1,000-2,000 birds were seen arriving to drink over a three hour period (Roger Potts, pers.comm.).

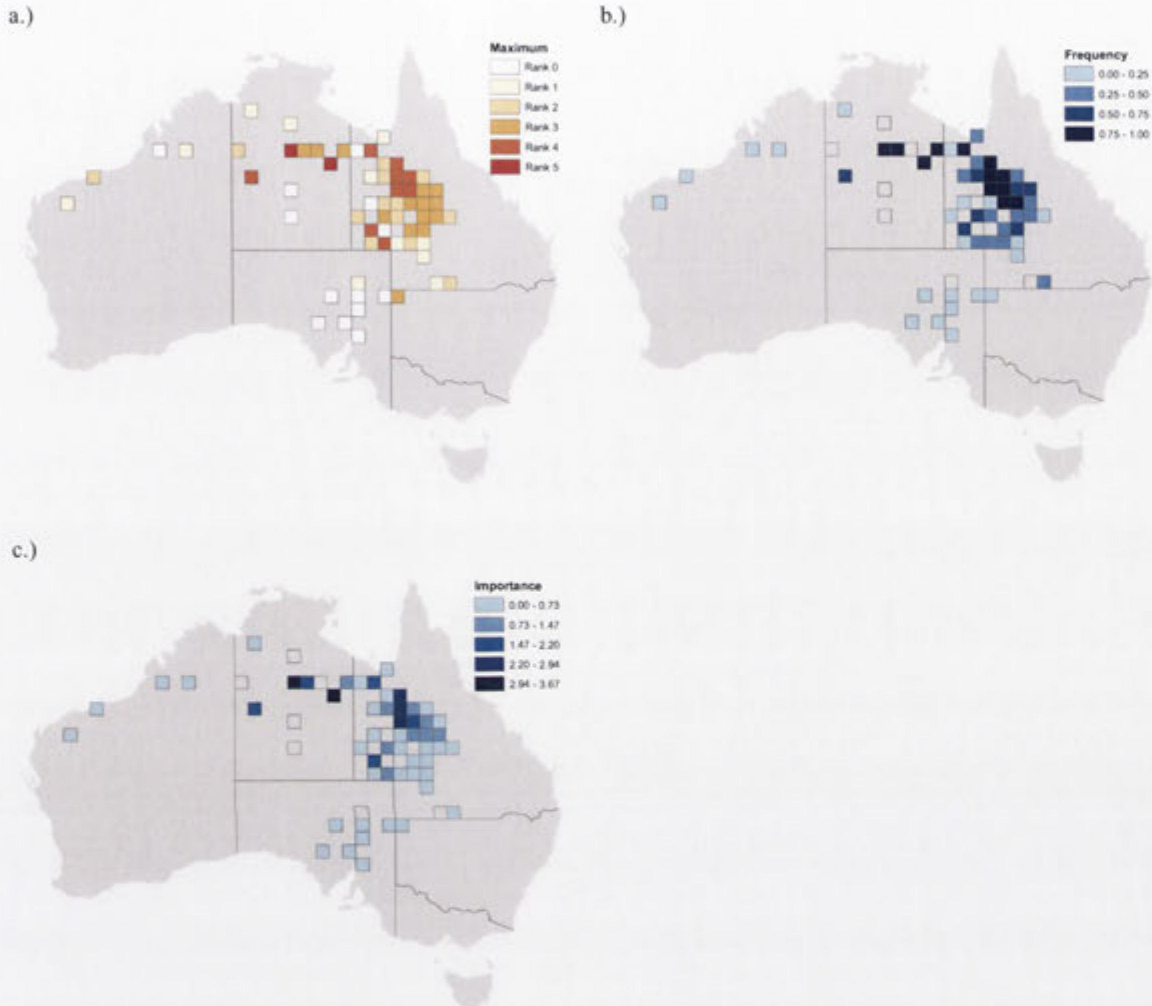


Figure 6.6 Distribution of three metrics derived from survey of abundance ranks of Flock Bronzewing Pigeons from January 2006-June 2007.

a) Maximum abundance ranks per degree cell, b) relative frequency i.e. for each degree cell number of months with pigeons present divided by number of months with survey data (min. n=5), c) relative importance i.e. sum of maximum abundance ranks divided by number of months with survey data (min. n=5).

The distribution of maximum abundance ranks per degree cell varied seasonally (Figure 6.7). These data provides no evidence of strong seasonal movement patterns.

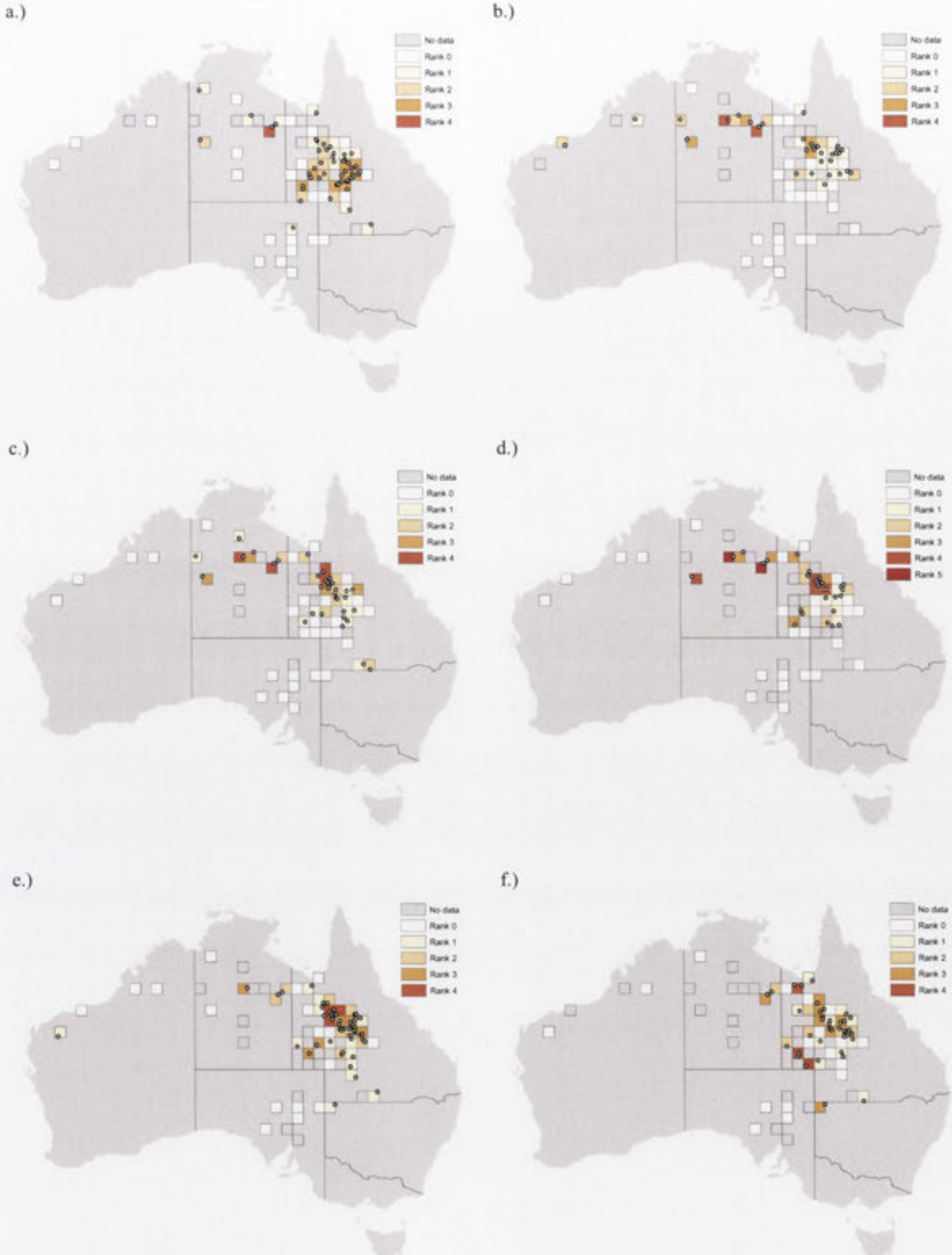


Figure 6.7 Distribution of maximum abundance ranks and properties with records of Flock Bronzewing Pigeons for six three monthly survey intervals.

a.) January, February, March 2006, b.) April, May, June 2006, c.) July, August, September 2006, d.) October, November, December 2006, e.) January, February, March 2007, f.) April, May, June 2007.

6.3.3 Survey results by block

There were 47 survey reports of Flock Bronzewing Pigeon abundance from five properties on the Barkly Tableland, N.T. Numbers of Flock Bronzewing Pigeons were observed to increase throughout 2006 to a maximum in November and December (Figure 6.8a), but few data were available for this block subsequently. Data for the Barkly Tableland survey block are relatively sparse but are congruent with trends from site-specific studies. Numbers of Flock Bronzewing Pigeons on Alexandria Station in the eastern Barkly declined from the late dry season 2006 to relatively low numbers in the early dry season 2007, suggesting large-scale dispersal prior to or during the wet season (see Appendix 2). This pattern is mirrored by observations on Helen Springs Station in the western Barkly.

There were 152 reports of Flock Bronzewing Pigeon abundance from 16 properties in the northern Mitchell grass survey block in the 18 month survey period. Results are broadly similar to those from the Barkly Tableland. There were reports of only small numbers in early 2006, but the proportion of high abundance ranks increased throughout the year and declined over the wet season to lower levels in the early dry season 2007 (Figure 6.8b).

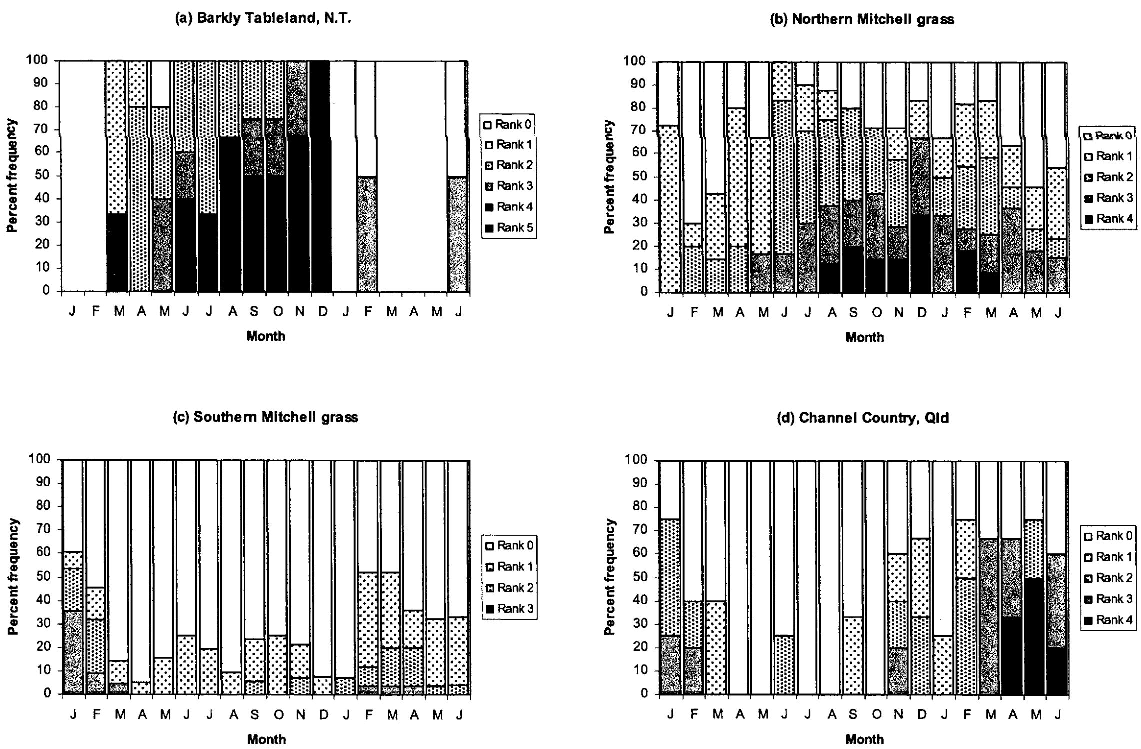


Figure 6.8 Percent frequency of abundance ranks in four survey blocks.

(a) Barkly Tableland, N.T. (*n*=5); (b) Northern Mitchell grass, Qld (*n*=16); (c) Southern Mitchell grass (*n*=36); (d) Channel Country, south-west Qld (*n*=8), January 2006 to June 2007. Data for Barkly Tableland with single records not shown.

There were 371 reports of Flock Bronzewing Pigeon abundance from 36 properties in the southern Mitchell grass survey block. There was an influx of Flock Bronzewing Pigeons into the Longreach region following unseasonal winter rainfall in June 2005, coinciding with the departure of birds from the Channel Country region. They were present in large numbers on several properties including Notus Downs and Eldwick Stations. About 3,000 Flock Bronzewing Pigeons arrived at Notus Downs Station south of Longreach in October 2005. The property owner had never seen them before in her time on the property since 1967 (P. Dean pers. comm. 17 January 2006). These birds remained in the area for 4-5 months until dispersed by summer rainfall, and very few remained by March 2006 (Figure 6.8c). There were no reports of breeding during this time. Flock Bronzewing Pigeons were reported to congregate throughout the day on the fringe of stock dams. Small numbers reappeared in the late wet season 2007.

There were 78 reports of Flock Bronzewing Pigeon abundance from eight properties in the Channel Country survey block. Flock Bronzewing Pigeons were present in small numbers in January and February 2006, thereafter were mostly not recorded until November 2006. Heavy local rainfall in the Bedourie area in January 2007 led to substantial flooding of Eyre Creek in the Georgina system and elsewhere in the Channel Country, and numbers increased by the mid-dry season (Figure 6.8d). There were subsequent (i.e. after the conclusion of this survey) reports later in the dry season of enormous aggregations in the Bedourie area (Forsyth 2007, Angus Emmott pers. comm.). Prior to this survey Flock Bronzewing Pigeons were reported as regular visitors to the area with numbers increasing throughout the dry season to a maximum prior to wet season rainfall (J. Cobb pers. comm.). Pastoral managers reported large numbers of Flock Bronzewing Pigeons on the floodplains of Channel Country cattle stations, which dispersed after heavy local rainfall in June 2005.

> Several weeks ago on the Georgina floodplains at Sandringham Station you could easily see three of four flocks on the wing at the one time and each flock well over 1,000 birds (G. Campbell pers. comm. 20 June 2005).

> Diamantina and Georgina country too wet to drive around but the big flocks seem to have now widely dispersed since the rain (G. Campbell pers. comm. 8 August 2005).

Aggregations estimated to be in the tens of thousands were observed in the Eyre Creek area south of Bedourie in December 2005 prior to the survey period.

6.3.4 Relationship between pigeon abundance and landscape productivity

Cross-correlation analyses suggested correlations between GPP and maximum abundance ranks in all survey blocks. In the northern Mitchell grass survey block the correlation coefficient had a maximum value of 0.55 at a lag of 7 months; in the Channel Country survey block the correlation coefficient had a maximum value of 0.56 at a lag of 2 months. Correlations between deviation from mean monthly GPP and maximum abundance rank were stronger in three of four survey blocks (Table 6.4, Figure 6.9).

Relationships were visually evident between patterns of rainfall, GPP, deviation from mean monthly GPP and the lagged distribution of maximum abundance ranks per degree cell. This is illustrated in Figures 6.10, 6.11 and 6.12.

Table 6.4 Results of cross-correlation analyses of monthly GPP, and deviation from mean monthly GPP, and maximum abundance ranks in four survey blocks.

	GPP		Deviation mean GPP	
Block	**Corr. coefficient (lag 0)**	**Corr. coeffiient (lag x)**	**Corr. coefficient (lag 0)**	**Corr. coefficient (lag x)**
Barkly Tableland, N.T.	-0.10	0.41 (7)	0.48	0.65 (1)
Northern Mitchell grass, Qld	-0.01	0.55 (7)	0.25	0.57 (4)
Southern Mitchell grass, Qld	<0.01	0.44 (10)	-0.23	0.27 (4)
Channel Country, Qld	0.41	0.56 (2)	0.43	0.70 (2)

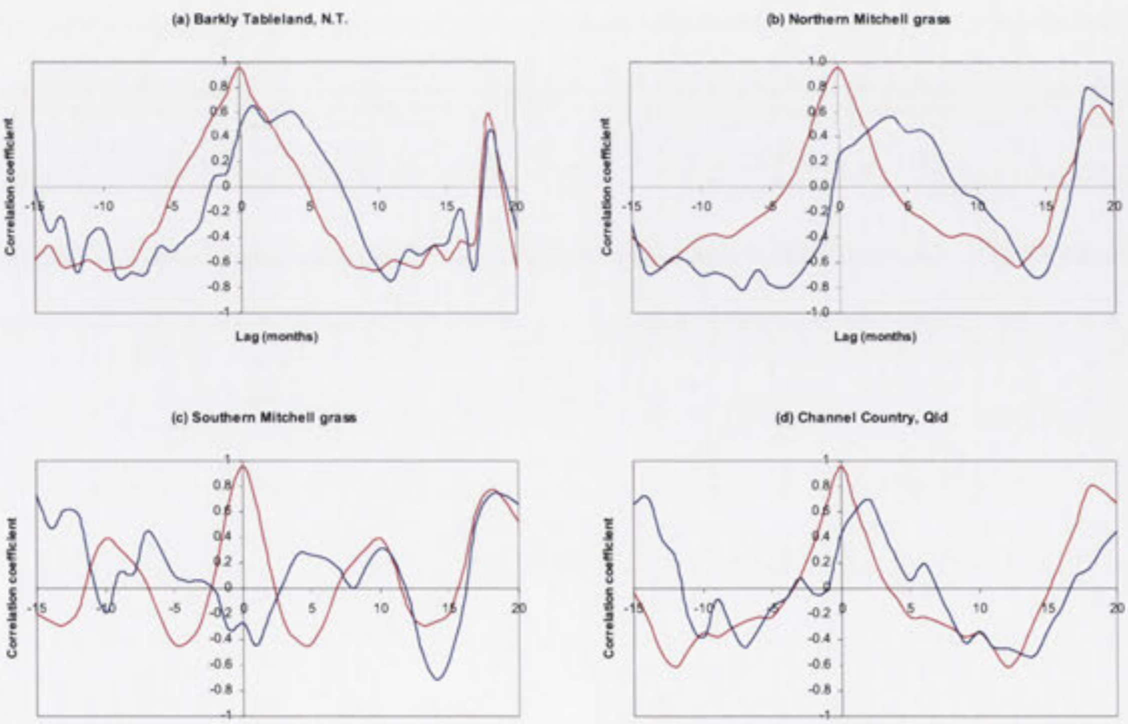


Figure 6.9 Results of cross-correlation analyses of deviation of monthly mean GPP and maximum abundance ranks for four survey blocks.

GPP data derived from intersection of time-series GPP imagery and 1,000 randomly selected points. Red = values of auto-correlation of deviation of monthly mean GPP; blue line = values of cross-correlation of deviation of monthly mean GPP and maximum abundance ranks.

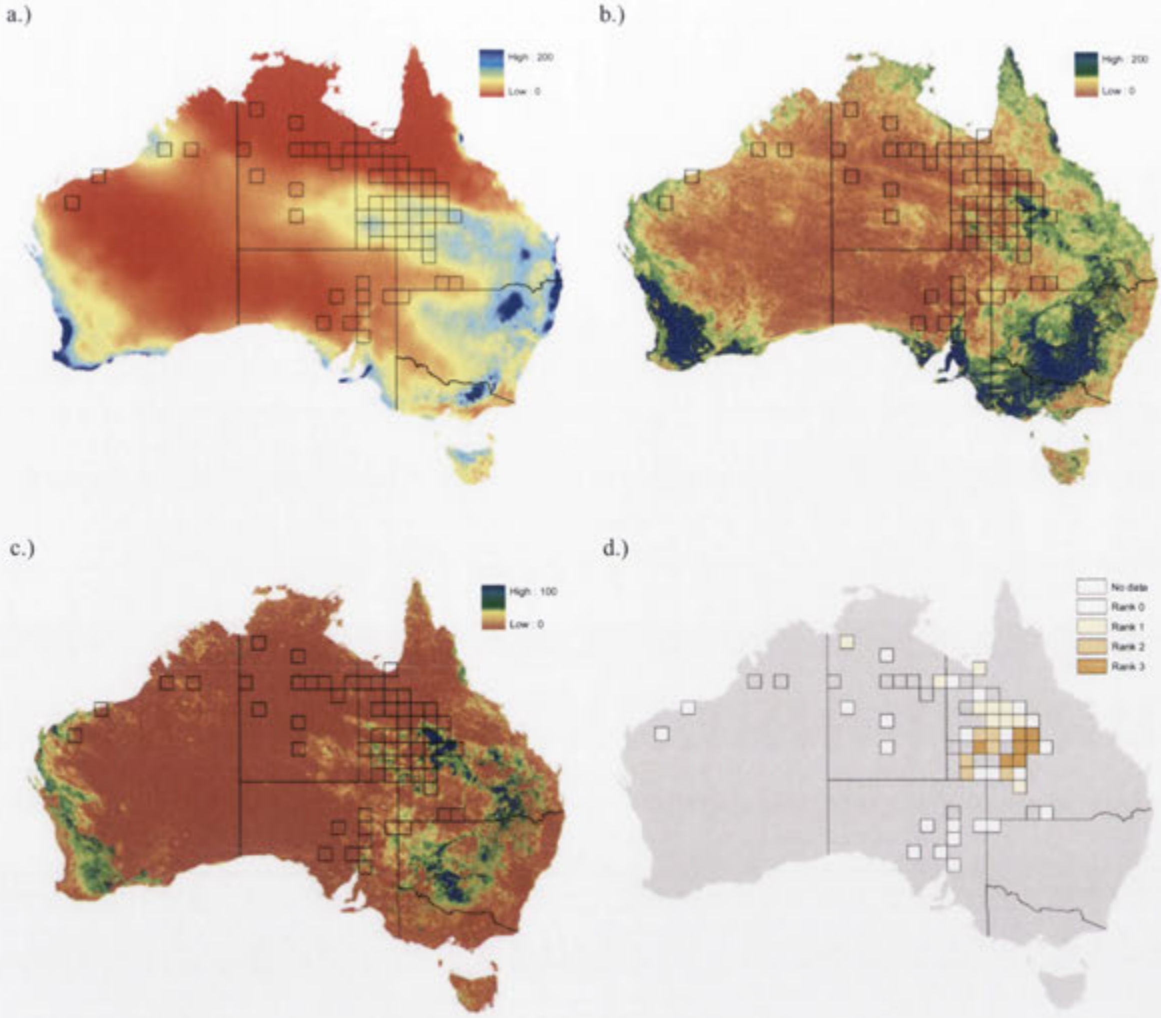


Figure 6.10 Relationship between rainfall, GPP and Flock Bronzewing Pigeon abundance.

a.) Interpolated rainfall surface June 2005, b.) GPP of ephemeral vegetation August 2005, c.) positive deviations from mean GPP August 2005, d.) distribution of Flock Bronzewing Pigeons shown as maximum abundance rank per degree cell of latitude and longitude January 2006.

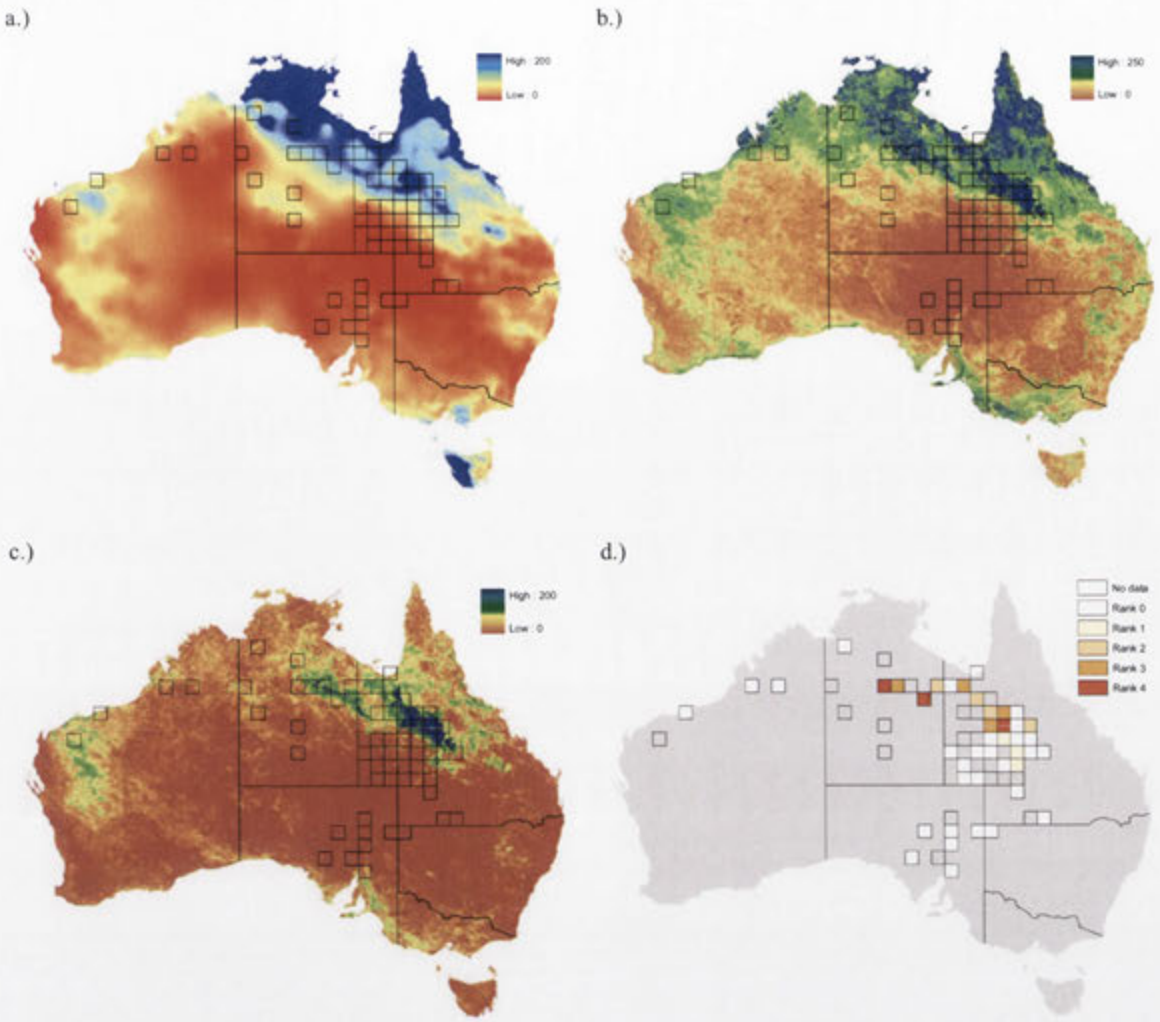


Figure 6.11 Relationship between rainfall, GPP and Flock Bronzewing Pigeon abundance.

a.) Interpolated rainfall surface April 2006, b.) GPP of ephemeral vegetation May 2006, c.) positive deviations from mean GPP May 2006, d.) distribution of Flock Bronzewing Pigeons shown as maximum abundance rank per degree cell of latitude and longitude October 2006.

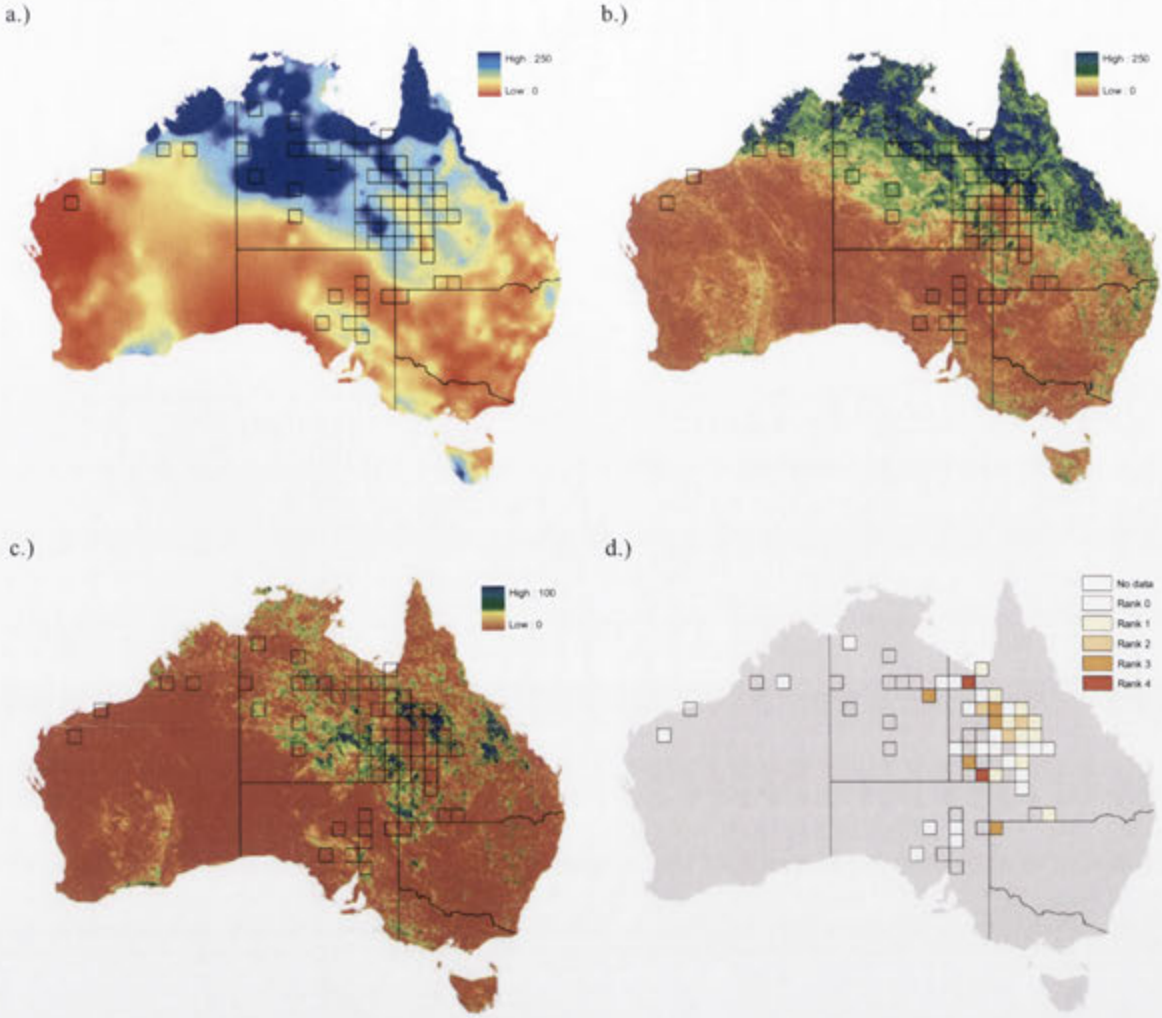


Figure 6.12 Relationship between rainfall, GPP and Flock Bronzewing Pigeon abundance.

a.) Interpolated rainfall surface January 2007, b.) GPP of ephemeral vegetation February 2007, c.) positive deviations from mean GPP February 2007, d.) distribution of Flock Bronzewing Pigeons shown as maximum abundance rank per degree cell of latitude and longitude June 2007.

6.4 DISCUSSION

This study demonstrates that community-based surveys can play a significant role in ecological studies in the sparsely populated rangelands of inland Australia, and may form the basis for on-going biodiversity monitoring in rangelands. Such programs will need careful planning to guarantee long-term participation and adequate spatial representation. Data value could be maximised by including multiple target species of rangeland conservation interest e.g. Flock Bronzewing Pigeon, Emu, Brolga, Australian Bustard.

The survey data provided evidence from three metrics that the core of the distribution of Flock Bronzewing Pigeons is centred on the Mitchell grasslands of the Barkly Tableland in the Northern Territory and the northern section of the Mitchell grasslands in Queensland. These results are congruent with results derived from analysis of database and atlas records (Chapter 3), and lend support to the notion proposed by Parker (1969) and Frith (1982) that these northern grasslands constitute core habitat. However, both fail to acknowledge the importance of Channel Country floodplains as habitat for the species and the nature and extent of dispersive movements.

The study provided no substantial evidence of seasonal movement patterns, and counters suggestions from mail-out survey data of a seasonal latitudinal shift in distribution. Rather, the results suggest that movements are irregular and linked to broad-scale patterns of rainfall and pulses of plant productivity. The survey provided evidence of movement episodes including (i) an exodus of aggregations from far south-west Queensland following unseasonal rainfall in mid-June 2005 and the consequent appearance of large numbers on the Mitchell grass downs of central Queensland which persisted until dispersed by summer rainfall in February 2006; (ii) a gradual increase in numbers in northern regions following late wet season rainfall from post-cyclonic depressions, which diminished during or after the wet season of 2006/07; (iii) the reappearance of large numbers months after extensive flooding in the Eyre Creek system in January 2007; and (iv) the appearance of large numbers in north-west New South Wales in mid-2007 following rainfall from the same weather system. In addition, a major influx of Flock Bronzewing Pigeons was reported in the Cunnamulla region on the southern fringe of their range after substantial drought-breaking summer rainfall in 2007/08, after an absence of several decades. Local observers reported that similar numbers had not been seen in the area since the 1950s, and prior to that, since the 1930s. Most events share the common features of drought or below average conditions followed by an above average or extended wet season, or significant flooding. For example, on the Barkly Tableland the wet season of 2005/06 was boosted by late rainfall from post-cyclonic depressions and was preceded by an extremely dry year, similar conditions had not been observed since 2000/01.

There are several references in the historic literature to the phenomenon of the appearance of large numbers of Flock Bronzewing Pigeons in the aftermath of drought (MacGillivray 1932, North 1913, McAllan 1996). Presumably this behaviour may be associated with periodic pulses of seed production from the ephemeral and annual components of grassland communities dominated by perennial tussock grasses. North (1913) quoted an informant from the Nyngan area in New South Wales:

> The Harlequin Bronze-wing usually appears in this district immediately upon the break up of drought, when heavy rains make the 'wild sago' grow, which is the first herbage to make its appearance. Then they come in great numbers, and stay several months, breeding in the meanwhile (North 1913).

Herbaceous plants in arid and semiarid ecosystems respond to pulses of precipitation by producing large quantities of seed (Holmgren *et al.* 2006) though long-term data on seed banks in Australian rangelands, and specifically black-soil perennial grasslands, are lacking. The long-term dynamics of Mitchell grass communities are poorly described, and are mostly confined to demographic analysis of the dominant perennial species under grazing by sheep (Orr 1980a, 1980b, Orr and Evenson 1991). Available data suggest that the biomass of annual grasses, perennial grasses, and forbs in grassland communities varies between years and that rainfall exerts a major influence on community composition (Foran and Bastin 1984, Ford 1992). Heavy grazing and reduced rainfall reduces the competitive dominance of perennial grasses.

There are also frequent references to the ephemeral nature of aggregations. In the survey there were several observations that Flock Bronzewing Pigeons were flushed from the area by rainfall in the early wet season, and indeed at other times. Rainfall can result in germination of seeds and food depletion. Whether this dispersal response is mediated by ambient levels of food availability or physiological state is unknown. Flock Bronzewing Pigeon populations appear to be in constant flux across the landscape in response to a mosaic of habitat patches that are dispersed and ephemeral. Despite the apparent vastness of tussock grassland dominated landscapes, it may that be that suitable habitat results only from the rare conjunction of particular soil and plant communities, and long-term rainfall patterns that favour high seed yields of favoured food plants.

The results of the survey presented here constitute a sound foundation for further studies. Much further work is required to examine the dynamics of resource and habitat use throughout their range, and the details of the phenomena of large-scale movement. There are many additional questions which need to be answered including the timing of movement responses in relation to rainfall and primary productivity, and the life-time movement tracks of individuals from within different portions of the occupied range. Such questions are not readily resolved, and require the integration of satellite telemetry and appropriately-scaled imagery.

6.5 SUMMARY OF FINDINGS AND CONCLUSIONS

Patterns of distribution and abundance of Flock Bronzewing Pigeons were examined using data provided by rangeland residents throughout the range of the species. Pastoralists and local residents were contacted at monthly intervals over eighteen months and asked to score the relative abundance of Flock Bronzewing Pigeons on their property. The survey yielded more than 1,200 responses from 118 observers from within 62 one-degree cells of latitude and longitude spanning the range of the species. Most reports (67%) noted the local absence of Flock Bronzewing Pigeons: there were relatively few records of high abundance ranks.

Distribution data from the survey were examined in relation to temporal patterns of plant productivity. Spatial differences in patterns of relative abundance were examined using data from four blocks of one-degree cells covering the Mitchell grass plains of the Barkly Tableland in the Northern Territory, northern Mitchell grass plains in Queensland, southern Mitchell grass plains in Queensland, and the Channel Country in south-west Queensland. Temporal patterns of abundance varied between blocks.

The data provided no evidence of large-scale seasonal movements; there was, however, evidence of large-scale reconfiguration of populations in response to pulses of plant productivity. The overall movement strategy appears to be serial, short-term invasion of resource rich patches which occur infrequently in the landscape, and which may result from the post-drought response of ephemeral plants. The details of large-scale movement behaviours are unresolved and require data from satellite-telemetry.

Chapter 7: FOOD OF THE FLOCK BRONZEWING PIGEON

7.1 INTRODUCTION

Identifying and quantifying the food resources of an organism is critical in the process of understanding the ecology of the organism. To date, there is remarkably little information on seasonal and geographic variation in the composition of the food of Flock Bronzewing Pigeons. The sole study that focused on diet in this species is Frith *et al.* (1976), who presented data based on analysis of crops of 49 birds collected in the Northern Territory, but did not consider geographic or temporal differences, and even suggest that the data may not represent the normal feeding habits of Flock Bronzewing Pigeons. In pooled samples from Elliot on the Barkly Tableland and from the Victoria River District, collected on unspecified dates between September 1965 and August 1966, Frith *et al.* (1976) identified the seed of at least 28 plant species, most of which were ephemeral herbs. The diet was dominated by taxa belonging to the families Euphorbiaceae, Boraginaceae, Poaceae and Asteraceae. Frith *et al.* (1976) suggested that much of the seed may have been foraged from cattle dung at cattle watering points, and that the data "reflect the grazing habits of cattle in drought as much as . . . the normal feeding habits of the pigeons". Given that this is the only study of diet in this species, this supposition has been repeated elsewhere (Lindsey 1995, Higgins and Davies 1996) but seems unlikely given that the principal plant species are relatively unpalatable to stock (Milson 2000), and that seed at the time of specimen collection lies on the soil surface rather than being held on the long-dead plant.

There are several, more anecdotal, mentions of the food and foraging habitat of Flock Bronzewing Pigeons in the early ornithological literature. Most fail to specify the identity of food plants. Seeds of grasses do not feature prominently with the exception of the records of Sturt and MacGillivray from western New South Wales, both of which refer to large numbers of birds feeding on seeds of grasses associated with floodplains. Sturt observed Flock Bronzewing Pigeons in the Frome Creek area feeding "upon the seed of the rice-grass" in January 1845. His companion Browne noted that:

> This country is tolerably well-covered with a kind of grass which is here peculiar to such localities. It is a summer grass the seed being ripe about January . . . Thousands of Parrots, Pigeons, Doves and Cockatoos live on these seeds when they are ripe, and, the harvest being over all go away about North West in immense flights . . . [and also that local aboriginal people

> were] all living on the seeds of a kind of Rice which grew abundantly on the flooded lands near the creeks (Finniss 1966, cited in McAllan 1996).

MacGillivray (1929) also refers to Flock Bronzewing Pigeons feeding on seeds of grasses growing on post-flooded alluvial flats. In unpublished notebooks MacGillivray referred to this plant as a tall growing grass which bore plentiful seed (McAllan 1996). McAllan (1996) considered this "rice-grass" to be the perennial tussock grass *Panicum decompositum* (known as Native Millet), though the birds may also have been feeding on the seed of associated plants and not necessarily solely on *P. decompositum*. Keartland noted large flocks of Flock Bronzewing Pigeons feeding amongst Flinders grass (*Iseilema* sp.) in the late 1890s and inferred that they had been feeding on Flinders grass seed (North 1898).

Mathews (1909) collected three specimens from Parry's Creek near Wyndham in Western Australia and noted that "the stomach contained seeds of the pea-bush, native rice, and a quantity of other larger seeds" suggesting that the feeding habitat was seasonally inundated grassland. Specimens collected by MacGillivray from Hewart Downs Station in north-west NSW contained "seeds like trefoil" (*Swainsona procumbens*) and unknown "fine cylindrical rough seeds" (notebook of W.D.K. MacGillivray, cited in McAllan 1996). Four specimens collected from Brunchilly station in the western Barkly Tableland in late February and early March 1966 contained "large numbers of seeds", and "small red brown seeds appears to be complete diet" (McEvey 1966). This seed may possibly be *Wedelia asperrima* (Asteraceae) which was noted as a "grassland herb forming (a) prominent layer" though late February might be too early for seed fall for this species. At the time Flock Bronzewing Pigeons were described as being present in small numbers only, but that it "became very numerous in April when flocks of up 1,500 were seen" (McEvey 1966).

There are two published records of feeding on burnt ground. The naturalist John Gilbert on Leichhardt's expedition to Port Essington noted flocks rising from burnt grass in the Burdekin valley in Queensland in April 1845 (Chisholm 1945). Carter (1902) observed them:

> . . . closely packed and busily feeding on the bare, burnt plain, evidently finding abundance of grass seeds in the cracks of the clayey soil (Carter 1902).

Fire is now largely absent from the primary habitat of the species due to active suppression by landholders (Holt and Bertram 1981). Fire is an important determinant of spatial patterning of granivorous birds in tropical woodlands in northern Australia by exposing the ground surface and allowing foragers access to fallen seed (Woinarski 1990), though its role in influencing foraging site selection by granivorous birds and seed resource dynamics in tussock grasslands remains unexplored.

More recent reports include incidental observations of birds seen feeding at sites in South Australia. Read (1991) observed a flock of 35 birds feeding on the immature fruits of Pop Saltbush *Atriplex spongiosa* at a site in north-east South Australia, while Reid (1988) observed feeding on fallen seed of *Phyllanthus lacunarius* which grows after summer rains on the fringing dunes of the Cooper floodplains in South Australia. Table 7.1 summarises published references to dietary habits of Flock Bronzewing Pigeons; and Table 7.2 presents a collation of all previous records of recorded dietary items in this species.

Whilst these disparate records contain some clues on the feeding habitat and foods of Flock Bronzewing Pigeons, there is a clear need for detailed studies to examine temporal variation in the composition of the diet at sites throughout their geographic range. This study examines variation in food of Flock Bronzewing Pigeons over a 15 month period at a site in Mitchell grasslands on the Barkly Tableland in the Northern Territory. Data from a smaller sample of specimens collected at a site in the Channel Country in south-west Queensland provide a limited basis for spatial comparison. This chapter addresses the questions:

(1) How do dietary patterns in the Flock Bronzewing Pigeon vary seasonally and between years?

(2) How do dietary patterns of this species vary spatially?

Table 7.1 Published records on food and feeding behaviour of Flock Bronzewing Pigeons.

Date of observation	Observer	Locality	Comments	Reference
Dec 1839	J. Gould	Namoi valley, NSW	"On dissecting the specimens obtained, I found their crops half filled with small hard seeds, which they procured from the open plains, but of what kinds I was unable to determine."	Gould (1841), cited in McAllan (1996)
Jan 1845	C. Sturt	Frome Creek area, western NSW	(Flock Bronzewing Pigeons feeding) "upon the seed of the rice-grass."	McAllan (1996)
1860s	W.D.K. MacGillivray	Darling River, near Paroo River overflow, NSW	(His father), "had seen a flock of over two miles in length rise from where they had been feeding on the seeds of the luxuriant grasses that came up after the flood waters had subsided."	MacGillivray (1929)
1860s	W.D.K. MacGillivray	Darling River, near Paroo River overflow, NSW	"At Kallara Station Paroo river in the sixties they came to feed on the Pappa grass a tall growing grass which bore plentiful seed."	Notebook of W.D.K. MacGillivray, cited in McAllan (1996)
1893	Informant to North	Narrabri area, NSW	"feeding around tanks and dams, chiefly on the seeds of the Nardoo plant (*Marsilea quadrifolia*)."	North (1913)
1896-97	G.A. Keartland	Fitzroy River, WA	"great flocks arose from amongst the Flinders grass, on the seeds of which they had been feeding."	North (1898)
Oct 1908	G.M. Mathews	Parry's Creek, near Wyndham, WA	"the stomach contained seeds of the pea-bush, native rice, and a quantity of other larger seeds."	Mathews (1909)
	K.H. Bennett	Mossgiel district, NSW	"Its food consists of the various seeds of herbaceous plants."	North (1913)
Feb-Mar 1966	A. McEvey	Brunchilly Station, NT	Contained "large numbers of seeds" and "small red brown seeds appears to be complete diet."	McEvey (1966)
Sept 1931	W.D.K. MacGillivray	Hewart Downs Station, NSW	One male collected 21/9/31 had empty crop, "and seeds like trefoil (*Swainsona procumbens*) in gizzard." Two birds collected 22/9/31 had crops filled with "fine cylindrical rough seeds."	Notebook of W.D.K. MacGillivray, cited in McAllan (1996)
	H. Frith	Victoria River District and near Elliot, Barkly, NT	Diet dominated by seed of three species of ephemeral herbs and an annual grass.	Frith *et al.* (1976)
Aug 1990	J. Read	Ulowarrina Waterhole, north-east SA	"One flock of 35 birds was observed feeding on immature fruits of Pop Saltbush *Atriplex spongiosa.*"	Read (1991)
	J. Reid		Observed feeding on seeds of *Phyllanthus lacunarius*	Reid (1988)

Table 7.2 Plant taxa previously recorded in the diet of the Flock Bronzewing Pigeon.

Family	Species	Reference
Asteraceae	*Wedelia asperrima*	Frith *et al.* (1976)
Boraginaceae	*Heliotropium* sp.	Frith *et al.* (1976)
Boraginaceae	*Trichodesma zeylanicum*	Frith *et al.* (1976)
Capparaceae	*Cleome viscosa*	Frith *et al.* (1976)
Chenopodiaceae	*Atriplex spongiosa*	Read (1991)
Commelinaceae	*Commelina* sp.	Frith *et al.* (1976)
Cucurbitaceae	*Cucumis myriocarpus*	Frith *et al.* (1976)
Cucurbitaceae	*Mukia maderaspatanus*	Frith *et al.* (1976)
Euphorbiaceae	*Euphorbia eremophila*	Frith *et al.* (1976)
Euphorbiaceae	*Phyllanthus lacunarius*	Reid (1988)
Euphorbiaceae	*Phyllanthus rhytidospermus*	Frith *et al.* (1976)
Fabaceae	*Aeschynomene indica*	Frith *et al.* (1976)
Fabaceae	*Desmodium muelleri*	Frith *et al.* (1976)
Fabaceae	*Lotus* sp.	Frith *et al.* (1976)
Malvaceae	*Abutilon* sp.	Frith *et al.* (1976)
Malvaceae	*Sida* sp.	Frith *et al.* (1976)
Marsiliaceae	*Marsilea* sp.	North (1913)
Mimosaceae	*Acacia* sp.	Frith *et al.* (1976)
Poaceae	*Tragus* sp.	Frith *et al.* (1976)
Poaceae	*Chionachne cyathopoda*	Frith *et al.* (1976)
Poaceae	*Dactyloctenium radulans*	Frith *et al.* (1976)
Poaceae	*Enneapogon* sp.	Frith *et al.* (1976)
Poaceae	*Panicum decompositum*	Frith *et al.* (1976), McAllan (1996)
Poaceae	*Panicum* sp.	Frith *et al.* (1976)
Portulacaceae	*Calandrinia* sp.	Frith *et al.* (1976)
Rubiaceae	*Spermacoce* sp.	Frith *et al.* (1976)
Solanaceae	*Solanum* sp.	Frith *et al.* (1976)
Zygophyllaceae	*Tribulus* sp.	Frith *et al.* (1976)

7.2 METHODS

7.2.1 Sample collection

Attempts to obtain crop samples using non-destructive methods (Zann and Straw 1984, Dostine and Franklin 2002) were not successful due to signs of stress during handling. So, instead, small numbers of Flock Bronzewing Pigeons were collected destructively on six occasions at three-monthly intervals from June 2006 to September 2007 from Helen Springs Station in the Barkly Tableland region of the Northern Territory (total n = 17). These samples are augmented by the serendipitous discovery of bird remains following predation which included an intact dried gizzard containing seeds in the late wet season on 21st April 2006. A further three individuals were collected at Glengyle Station near Bedourie in south-west Queensland in late 2005. Birds were mostly collected by shooting in the late afternoon when flocks gathered to drink at watering points. Specimens were refrigerated in the field and subsequently kept frozen in the laboratory until analysis. Each bird was weighed using a Pesola spring balance and external features including wing length, head-bill length, and tarsal length were measured. The moult score of primary wing feathers was recorded. Age (juvenile, sub-adult, adult) and sex were estimated from plumage characteristics and gonad characteristics. Crop and gizzard contents were removed and stored separately in 70% ethanol and later sorted with the aid of a Leica Wild M8 stereo-microscope.

Seeds from the crop were enumerated and identified by comparison with known reference specimens. The length and width of 20 individual seeds of the main food species were measured to the nearest 0.1 mm using vernier calipers. Seed weights were measured by weighing bulk samples using a Mettler AE260 balance after being oven dried at 70°C for 24 hours.

7.2.2 Analyses

Data are presented as percentages of the total number of seeds per sample and in the total pooled sample, and the total dry weight of seeds per sample and in the total pooled sample. Dietary diversity for each sample was based on dry weight data and calculated as $(\Sigma P_i^2)^{-1}$ where P_i is the proportion of dry weight of food item i (Ludwig and Reynolds 1988).

Multivariate analyses of the food data was conducted using the PRIMER version 6 software package (Clarke and Gorley 2006). Dry weight data for individual birds was standardised and square root transformed. Compositional patterns were analysed using non-metric multi-dimensional scaling (MDS). Ordination coordinates were overlain by data for individual food types scaled appropriately to examine seasonal trends. Data are thus shown for species prominent in the early Dry season 2006 (*Phyllanthus lacerosus* and *Wedelia asperrima*); species prominent in the late Dry season 2006 (*Trichodesma zeylanicum*); species prominent in the early Dry season 2007 (*Chionachne hubbardiana*); and species prominent in the late Dry season 2007 (*Sida spinosa* and *Cucumis melo*).

Table 7.3 Number of collection records of main Flock Bronzewing Pigeon food plants obtained from various sources.

Species	Source	# records
Chionachne hubbardiana	Qld Herbarium	40
Chionachne hubbardiana	NT Herbarium	28
Chionachne hubbardiana	R. Fensham	17
Phyllanthus lacerosus	Qld Herbarium	12
Phyllanthus lacerosus	NT Herbarium	16
Phyllanthus lacerosus	R. Fensham	2
Wedelia asperrima	Qld Herbarium	49
Wedelia asperrima	NT Herbarium	59
Wedelia asperrima	R. Fensham	1
Trichodesma zeylanicum var. *latisepalum*	Qld Herbarium	25
Trichodesma zeylanicum var. *latisepalum*	NT Herbarium	42
Trichodesma zeylanicum	R. Fensham	17

Distributional records for four plant species found to be prominent in the food were obtained from the Queensland Herbarium, the Northern Territory Herbarium, and data presented in Fensham *et al.* (2000) (Table 7.3). There are three varieties of *Trichodesma zeylanicum* (Wheeler 1992); records of *T. zeylanicum* var. *latisepalum* were selected from herbaria data. The data from Fensham did not specify the variety of *T. zeylanicum*, but was used nevertheless, as all data were collected in Mitchell grass habitats. The geographic coordinates of records for each species were mapped using ArcGIS.

7.3 RESULTS

7.3.1 Barkly Tableland

At the Helen Springs site seeds from at least 35 species from 15 plant families were identified (Tables 7.4 and 7.5). Most food items were seeds of native grassland plants; crops contained only minute quantities of vegetative material and invertebrates. Seed of only four plants individually contributed more than 5% of the total number or total dry weight of food ingested by Flock Bronzewing Pigeons, and together comprised 94.1% of the total number of seeds and 92.3% of the total dry weight (Table 7.6). These included *Wedelia asperrima* (Asteraceae), *Trichodesma zeylanicum* (Boraginaceae), *Chionachne hubbardiana* (Poaceae), and *Phyllanthus lacerosus* (Euphorbiaceae). Photographs of the seed of these species are shown in Figure 7.1. Only six other plants contributed more than 0.5% of the total number of seeds, and only two contributed more than 1% of the total dry weight of food. Seed of *W. asperrima* was the most important food item numerically and contributed 43.2% of the total number of seeds but only 18.8% of the total dry weight of the food. On a dry weight basis seed of *Trichodesma zeylanicum* was the most important food item and contributed 44.4% of the total dry weight but only 18.4 % of the total number of seeds. Seeds of plants belonging to the Family Euphorbiaceae including *P. lacerosus*, *P. maderaspatensis* and *Leptopus decaisnei* comprised 28.1% of the total number of seeds and 9.1% of the total dry weight of food.

The single gizzard collected on 21st April 2006 contained seed of eight plants, including *Commelina tricarinata* (84.2% dry weight) and an unidentified species of Malvaceae (Table 7.7). The species present are characteristic of wetter parts of the landscape either in or on the fringes of bluebush swamps (Brock 2000).

The relative importance of the principal food plant species differed between samples (Figures 7.2 and 7.3). Diet in the early dry season of June 2006 was dominated by seed of *W. asperrima* and *P. lacerosus*, thereafter seed of *Trichodesma zeylanicum* was important until the early dry season of June 2007 when seed of *Chionachne hubbardiana* became important. The percentage of the total number of seeds consisting of these species differed between samples and ranged from 98.5% in June 2006 to 68.9% in September 2007. The overall temporal trend of a decline in percentage of total number of seeds consisting of these species was marginally non-significant (P=0.06). The percentage of the total dry weight consisting of these seeds differed between samples (range 81.8-97.2%, mean 92.2%). There was no significant temporal trend in the percentage of dry weight of seeds consisting of these species (P>0.05).

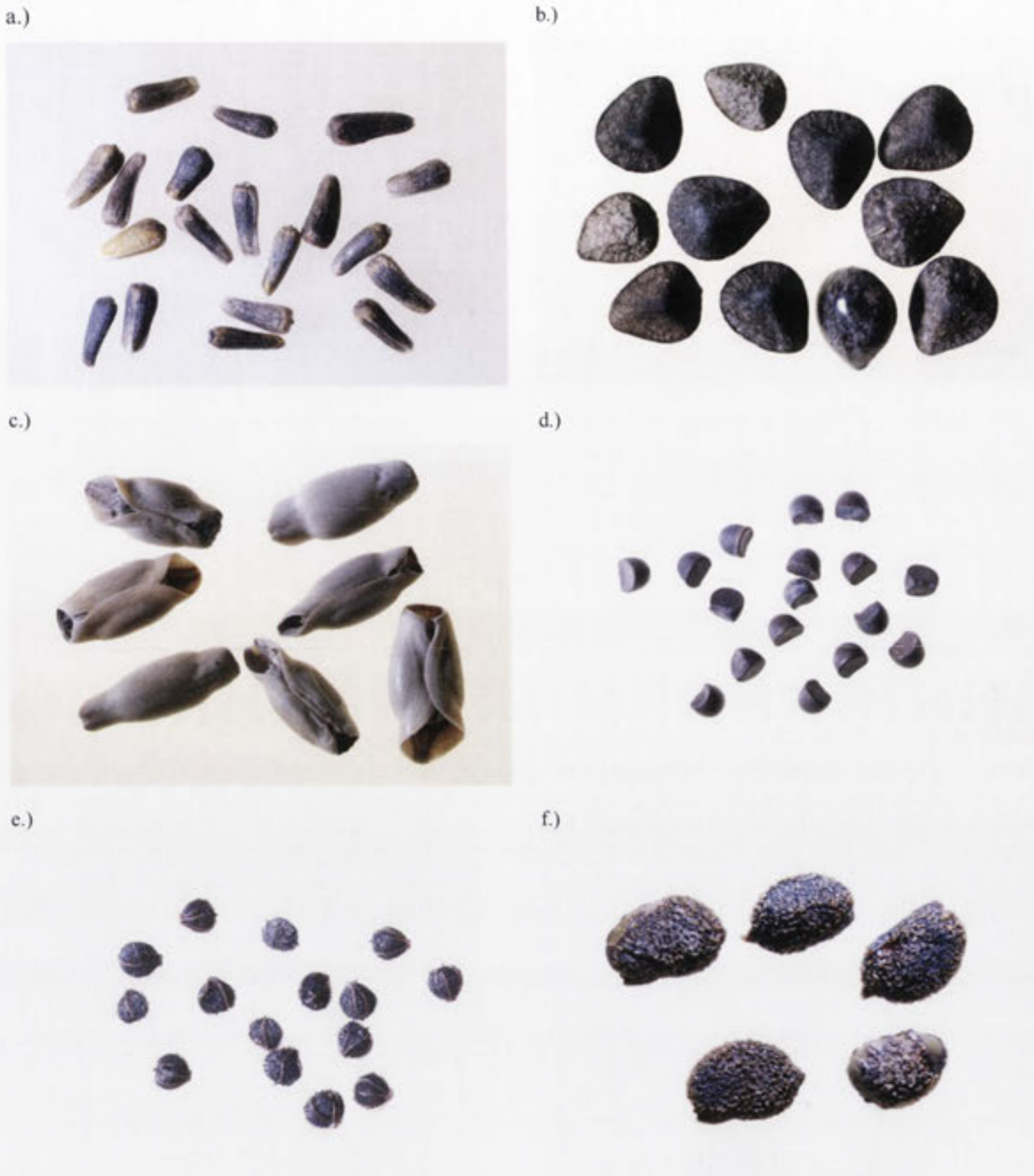


Figure 7.1 Seeds eaten by Flock Bronzewing Pigeons.

(a) *Wedelia asperrima* (Asteraceae); (b) *Trichodesma zeylanicum* (Boraginaceae); (c) *Chionachne hubbardiana* (Poaceae); (d) *Phyllanthus lacerosus* (Euphorbiaceae); (e) *Schoenoplectus dissachanthus* (Cyperaceae); (f) *Cullen cinereum* (Fabaceae).

Table 7.4 Percent number of food items in six samples and total pooled sample from Helen Springs Station, Northern Territory.

+ indicates present in trace amounts.

Food items	Jun 06	Sep 06	Dec 06	Mar 07	Jun 07	Sep 07	Total
Seeds							
Family Aizoaceae							
Trianthema sp.	0.02	0.02	0.10				0.02
Trianthema portulacastrum				0.73	0.14		0.10
Family Asteraceae							
Wedelia asperrima	58.87	41.12	5.20	1.14	28.36	2.86	43.15
Family Boraginaceae							
Heliotropium geocharis		0.05	0.20			0.13	0.02
Trichodesma zeylanicum	2.41	32.24	76.63	61.44	2.33	29.96	18.37
Family Capparaceae							
Cleome viscosa	0.08	0.07	1.94	0.05			0.13
Family Commelinaceae							
Commelina spp.	0.06	0.28	0.10	1.14		0.33	0.24
Family Cucurbitaceae							
Cucumis melo	0.05	0.02	0.10		3.08	12.32	0.74
Family Euphorbiaceae							
Euphorbia sp.	0.05	0.05		4.02			0.53
Leptopus decaisnei	0.35	1.79	0.92	1.09		0.33	0.70
Phyllanthus lacerosus	36.09	18.82	3.67	16.18	0.07	0.13	26.36
Phyllanthus maderaspatensis	0.14	1.00	1.43		0.34	1.00	0.36
Sauropus rhytidospermus		0.50					0.09
Family Fabaceae							
Alysicarpus muelleri			0.61				0.02
Cullen cinereum				0.51	0.07		0.06
Desmodium muelleri	0.01	0.05			0.07		0.02
Rhynchosia minima	0.28	0.10	0.82	1.14	0.96	10.39	0.86
Glycine falcata	0.23	2.55		0.91			0.70
Family Goodeniaceae							
Goodenia byrnesii						0.07	<0.01
Family Malvaceae							
Malvastrum americanum	0.01					1.26	0.06
Sida spinosa		0.12	1.94	0.48	1.99	4.46	0.43
Sida spp.			0.41	0.03		0.13	0.02
Hibiscus trionum		0.03		0.03	0.14		0.02
Family Poaceae							
Chionachne hubbardiana	1.17	0.72	5.71	6.52	62.40	35.95	6.22
Dactyloctenium radulans	0.08		0.10				0.05
Dicanthium sericeum	0.02						0.01
Echinochloa colonum		0.02					<0.01
Panicum decompositum	0.03	0.16		0.10			0.06
Paspalidium retiglume		0.03		4.35		0.60	0.56
Urochloa gilesi		0.19					0.03
Unid grass seeds	0.01	0.03		0.03	0.07		0.02
Family Nyctaginaceae							
Boerhavia sp.		0.02					<0.01
Family Portulacaceae							
Portulaca oleracea				0.08			0.01
Family Rubiaceae							
Spermacoce pogostoma	0.02	0.02				0.07	0.02

Table 7.4 cont.

Food items	Jun 06	Sep 06	Dec 06	Mar 07	Jun 07	Sep 07	Total
Family Tiliaceae							
Corchorus sp.	0.02		0.10				0.01
Unidentified plant seed				0.05			0.01
Other material							
Leaf fragments	+	+	+	+	+	+	
Hymenoptera		+					
Coleoptera				+			
Phthiraptera	+				+		
Odonata	+						
Orthoptera	+						
Total number seeds	18,915	5,803	980	3,955	1,460	1,502	32,615
Number of samples	4	4	3	2	2	2	17
Mean number seeds/crop	4,729	1,451	327	1,978	730	751	1,919

Table 7.5 Percent dry weight of food items in six samples and total pooled sample from Helen Springs Station, Northern Territory.

+ indicates present in trace amounts.

Food items	Jun 06	Sep 06	Dec 06	Mar 07	Jun 07	Sep 07	Total
Seeds							
Family Aizoaceae							
Trianthema sp.	<0.01	<0.01	<0.01				<0.01
Trianthema portulacastrum				0.11	0.02		0.03
Family Asteracae							
Wedelia asperrima	53.43	14.95	1.06	0.26	5.34	0.53	18.79
Family Boraginaceae							
Heliotropium geocharis		0.01	0.03			0.02	0.01
Trichodesma zeylanicum	12.13	65.13	86.61	77.46	2.43	30.88	44.44
Family Capparaceae							
Cleome viscosa	0.03	0.01	0.15	<0.01			0.02
Family Commelinaceae							
Commelina spp.	0.39	0.61	0.12	1.74		0.44	0.70
Family Cucurbitaceae							
Cucumis melo	0.12	0.02	0.06		1.67	6.60	0.93
Family Euphorbiaceae							
Euphorbia sp.	0.03	0.01		0.50			0.13
Leptopus decaisnei	0.19	0.40	0.11	0.15		0.04	0.19
Phyllanthus lacerosus	22.59	6.84	0.75	3.67	0.01	0.02	8.65
Phyllanthus maderaspatensis	0.04	0.10	0.08		0.02	0.05	0.04
Sauropus rhytidospermus		0.49					0.10
Family Fabaceae							
Alysicarpus muelleri			0.47				0.03
Cullen cinereum				0.35	0.03		0.08
Desmodium muelleri	0.03	0.05			0.04		0.02
Rhynchosia minima	1.08	0.20	0.86	1.14	0.94	9.43	1.78
Glycine falcata	1.65	8.96		2.02			2.84
Family Goodeniaceae							
Goodenia byrnesii						0.02	<0.01
Family Malvaceae							
Malvastrum americanum	0.00					0.22	0.02
Sida spinosa		0.06	0.65	0.18	0.59	1.14	0.28
Sida spp.			0.16	0.02		0.02	0.02
Hibiscus trionum		0.07		0.03	0.11		0.03
Family Poaceae							
Chionachne hubbardiana	8.01	1.99	8.78	11.18	88.71	50.40	20.46
Dactyloctenium radulans	0.03		<0.01				0.01
Dicanthium sericeum	0.01						<0.01
Echinochloa colonum		<0.01					<0.01
Panicum decompositum	0.02	0.02		0.01			0.01
Paspalidium retiglume		0.01		0.74		0.08	0.18
Urochloa gilesi		0.04					0.01
Unid. grass seeds	0.00	0.01		<0.01	<0.01		<0.01
Family Nyctaginaceae							
Boerhavia sp.		0.01					<0.01
Family Portulacaceae							
Portulaca oleracea				<0.01			<0.01
Family Rubiaceae							
Spermacoce pogostoma	0.01	<0.01				0.01	0.01

Table 7.5 cont.

Food items	Jun 06	Sep 06	Dec 06	Mar 07	Jun 07	Sep 07	Total
Family Tiliaceae							
Corchorus sp.	<0.01		<0.01				<0.01
Unidentified plant seed				0.05			0.01
Other material							
Leaf fragments	0.21	<0.01	0.10	0.40	0.10	0.07	0.18
Hymenoptera		+					
Coleoptera				+			
Phthiraptera	+				+		
Odonata	+						
Orthoptera	+						
Dry weight (mg)	37,515	28,727	8,671	31,373	13,967	14,570	134,822
Number of samples	4	4	3	2	2	2	17
Mean dry wt seeds/crop (mg)	9,379	7,179	2,890	15,687	6,984	7,285	
Dietary diversity	2.79	2.18	1.32	1.63	1.26	2.76	

Table 7.6 Number and dry weight of dominant food types in the food of Flock Bronzewing Pigeons.

Sample of 17 individuals collected from Helen Springs Station.

Plant taxa	No. of seeds	% No. seeds	Dry weight (mg)	% Dry wt
Wedelia asperrima (Asteraceae)	14,074	43.2	25,333	18.8
Phyllanthus lacerosus (Euphorbiaceae)	8,598	26.4	11,659	8.6
Trichodesma zeylanicum (Boraginaceae)	5,991	18.4	59,910	44.4
Chionachne hubbardiana (Poaceae)	2,028	6.2	27,581	20.5
Sub-total number of seeds	30,691	94.1	124,483	92.3
Total number of seeds	32,615		134,822	

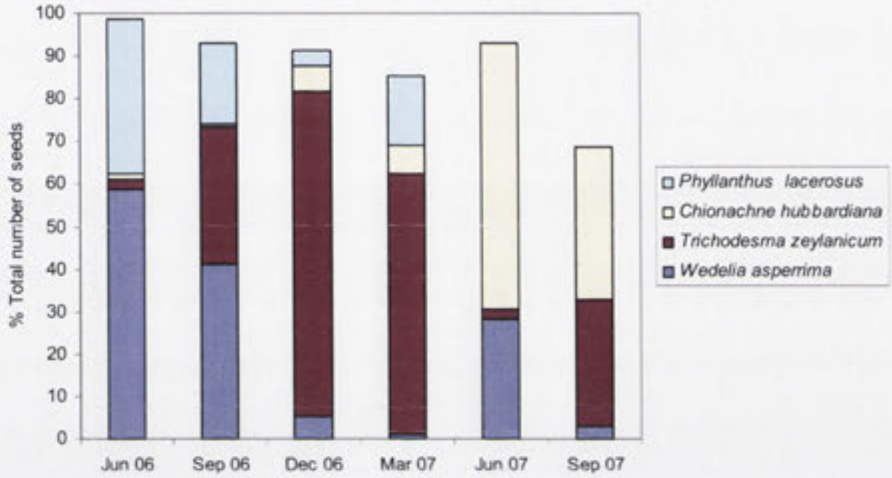


Figure 7.2 Seasonal variation in percent contribution by number of four principal seed types.

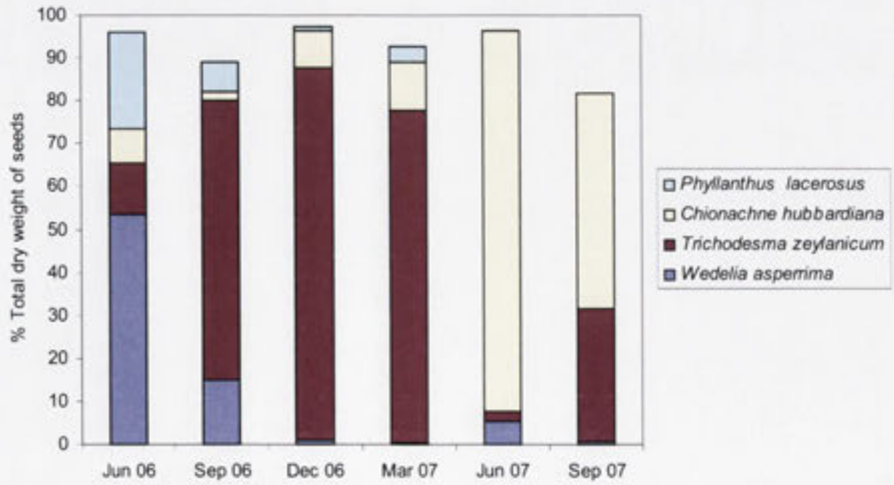


Figure 7.3 Seasonal variation in percent contribution by dry weight of four principal seed types.

Table 7.7 Percent number and percent dry weight of food items in Flock Bronzewing Pigeon gizzard collected on 21st April 2006 at Helen Springs Station.

Food items	% no.	% dry wt
Family Commelinaceae		
Commelina tricarinata	46.67	84.17
Family Capparaceae		
Cleome viscosa	12.38	0.13
Family Rubiaceae		
Spermacoce pogostoma	9.52	1.58
Family Malvaceae		
Sida spp.	2.86	1.07
Unid. seed	23.81	9.72
Family Cyperaceae		
Schoenoplectus dissachanthus	2.86	0.27
Family Fabaceae		
Cullen cinereum	0.95	0.80
Seed type family indet.	0.95	2.25
Number of seeds	105	
Dry weight (mg)	770	

MDS ordination of standardised square root transformed dry weight data revealed consistent grouping of individuals within samples with the exception of one individual in September 2006 (Figure 7.4). In contrast to the other individuals within this sample, the crop of this individual contained large numbers of *Phyllanthus lacerosus* seed and was the only specimen not to contain seed of both *Wedelia asperrima* and *Trichodesma zeylanicum*. The ordinations reveal a shift in the composition of the diet between seasons and years.

The number of seeds per crop varied between samples, but in a consistent manner within years. In 2006 seed numbers per crop declined from June (average 4,743, maximum 9,836) to December (average 326, maximum 620). In 2007 seed numbers per crop declined from March (average 1,977, maximum 2,598) to September (average 751, maximum 754). Dietary diversity varied between samples and was highest for samples from June 2006 and September 2007.

7.3.2 Channel Country, south-west Queensland

The seed of two plant species (the herb *Cullen cinereum* and the sedge *Schoenoplectus dissachanthus*) comprised over 99% of the total number of seeds identified in three crop samples collected from Glengyle Station in the Channel Country of south-west Queensland (Table 7.8). Photographs of the seed of these species are shown in Figures 7.1e and 7.1f. Both plants tend to favour wetter areas and are common on flooded areas during the drying phase

(Jessop 1981, Wheeler 1992). Both plants were abundant in suitable habitat on the Barkly Tableland, but seed of these plants was only a minor component of the food.

Table 7.8 Percent number of food items from crops of Flock Bronzewing Pigeons from Glengyle Station, Queensland.

Food items	18 Nov 05	11 Dec 05	11 Dec 05	Total
Family Cyperaceae				
Schoenoplectus dissachanthus	76.53	0.03	100.00	39.70
Family Fabaceae				
Cullen cinereum	23.09	99.71		59.98
Unidentified plant seeds (9 types)	0.25	0.21		0.33
Total number seeds	3,634	3,409	23	7,066

7.3.3 Seed morphology

The dimensions of the main seed types in the food ranged in length from 1.4-8.0 mm and in width from 1.4-3.3 mm (Table 7.9), though seeds as small as 1.1 mm in length (i.e. *Dactyloctenium radulans*) were eaten in small amounts. *Chionachne hubbardiana* had by far the heaviest seed. The kernel of *C. hubbardiana* comprised only 55.5% of the dry weight of the entire seed, and consequently the food of birds feeding on *C. hubbardiana* included a high proportion of non-nutritious plant fibre.

Table 7.9 Dimensions (mean ± s.d.) and dry weight of selected seeds eaten by Flock Bronzewing Pigeons.

Plant taxa	Length (mm)	Width (mm)	Dry wt (mg)
Chionachne hubbardiana	8.0 ± 0.6	3.3 ± 0.2	24.5
C. hubbardiana kernel	4.2 ± 0.2	2.9 ± 0.2	13.6
Trichodesma zeylanicum	3.9 ± 0.3	3.2 ± 0.2	10.0
Cullen cinereum	3.6 ± 0.2	2.3 ± 0.1	6.5
Paspalidium retiglume	3.0 ± 0.2	1.6 ± 0.1	1.9
Wedelia asperrima	3.3 ± 0.4	1.4 ± 0.1	1.8
Phyllanthus lacerosus (smooth seed)	1.7 ± 0.1	1.7 ± 0.1	1.8
Spermacoce pogostoma	2.3 ± 0.1	1.4 ± 0.1	1.4
Phyllanthus lacerosus (striated seed)	1.4 ± 0.1	1.4 ± 0.1	1.2
Panicum decompositum	2.1 ± 0.04	1.4 ± 0.05	1.1
Leptopus decaisnei	2.0 ± 0.1	1.5 ± 0.1	1.1
Schoenoplectus dissachanthus	1.5 ± 0.1	1.4 ± 0.1	0.5
P. maderaspatensis	1.3 ± 0.03	1.1 ± 0.04	0.5
Dactyloctenium radulans	1.1 ± 0.1	0.8 ± 0.1	0.4

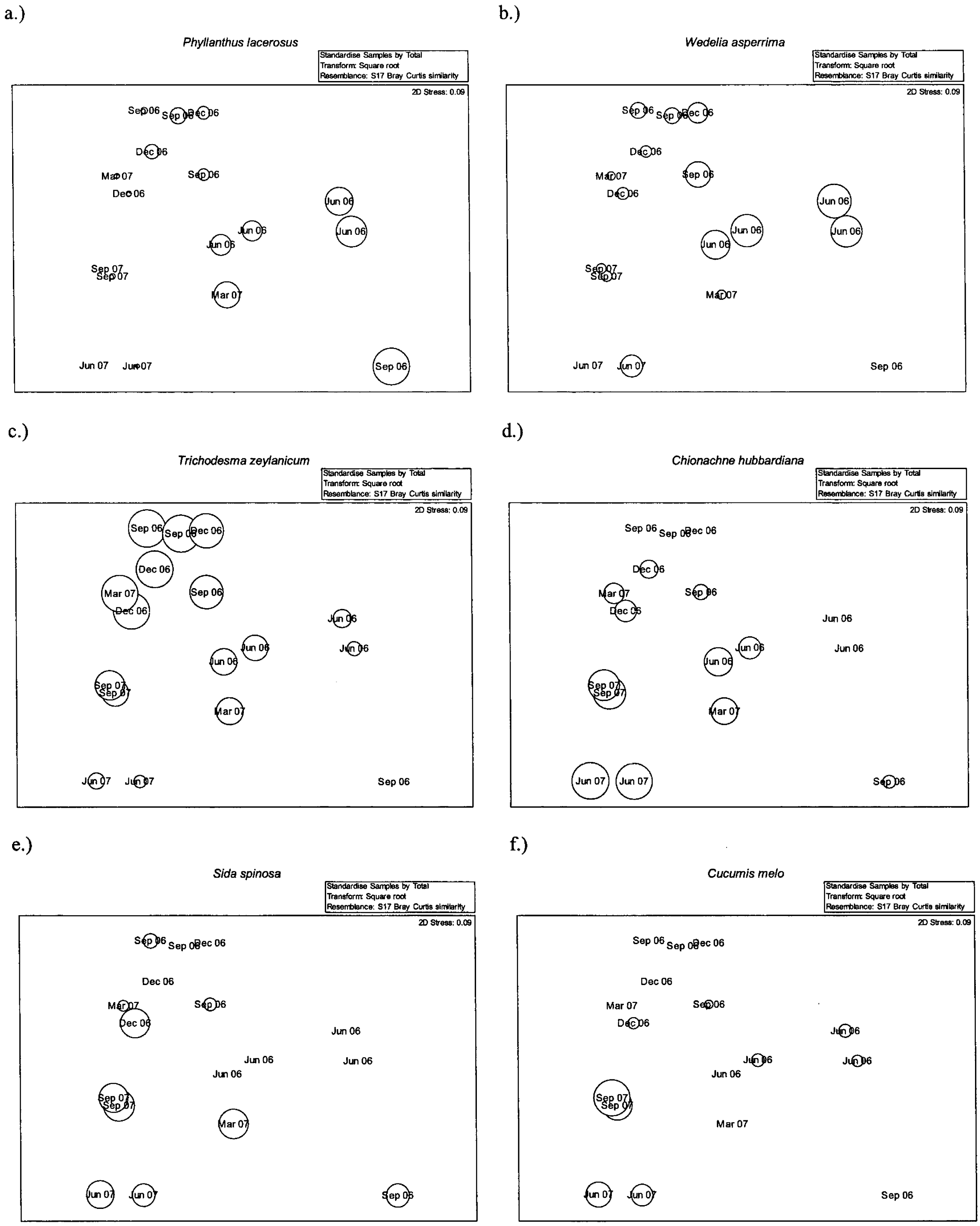


Figure 7.4 MDS ordination of standardised transformed dry weight data.

Bubble-plot of abundance of (a) *Phyllanthus lacerosus*; (b) *Wedelia asperrima*; (c) *Trichodesma zeylanicum*; (d) *Chionachne hubbardiana*; (e) *Sida spinosa*; (f) *Cucumis melo*. Bubble-plots indicate relative importance of seed types in food of 17 individual birds. Bubble size is scaled in proportion to transformed data; scaling identical for *P. lacerosus*, *W. asperrima*, *T. zeylanicum* and *C. hubbardiana* but magnified for *S. spinosa* and *C. melo*.

7.3.4 Distribution of dominant food plants

Locality records of the four dominant food plants are largely confined to the tropics (Figure 7.5). Three species (*Wedelia aperrima*, *Trichodesma zeylanicum* and *Chionachne hubbardiana*) show a marked affinity with Mitchell grasslands, and are most prevalent on the Barkly Tableland in the Northern Territory and the northern portion of the Mitchell grass area in Queensland. The fourth species (*Phyllanthus lacerosus*) has relatively few records and extends into northern New South Wales.

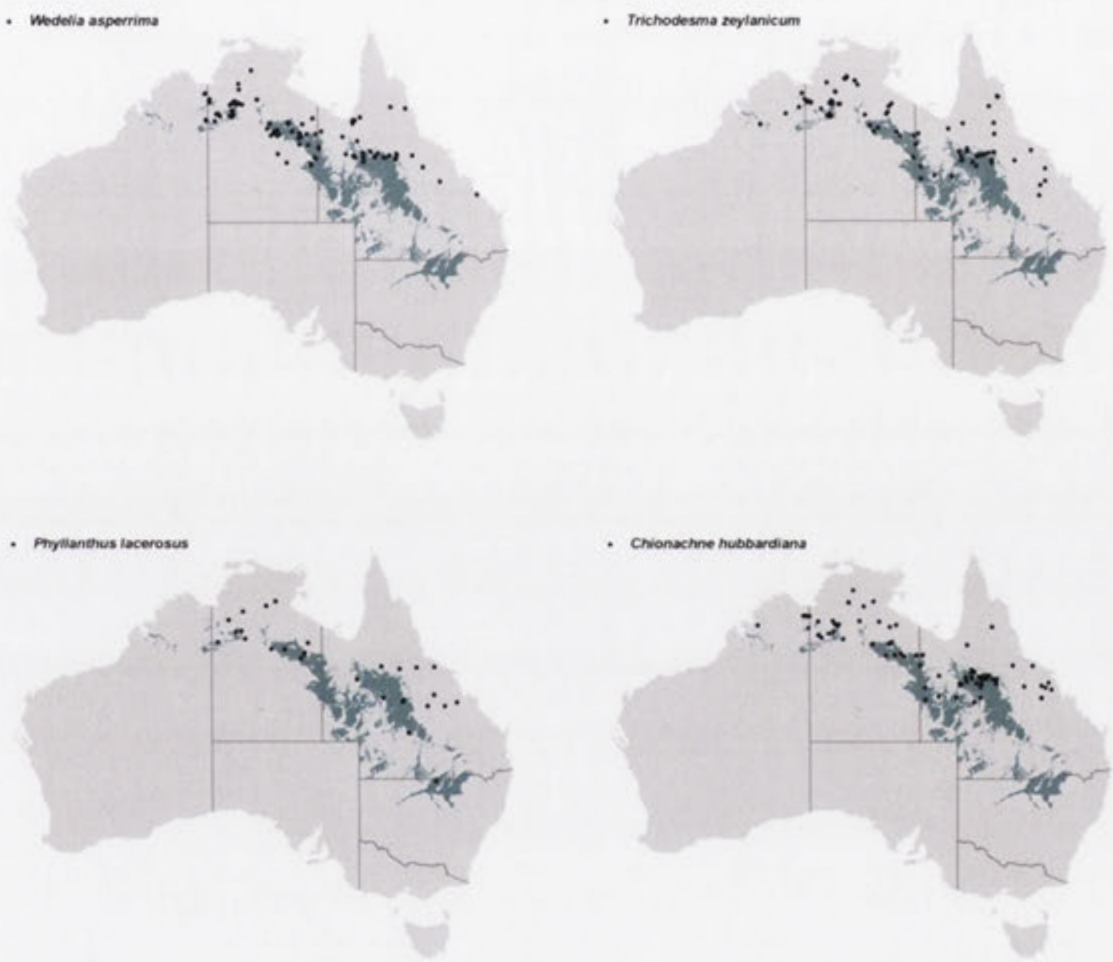


Figure 7.5 Distributions of four dominant food plants of the Flock Bronzewing Pigeon.

Mapped areas occupied by Mitchell grasslands shown in blue.

7.4 DISCUSSION

This study confirms, in part, and extends the findings of Frith *et al.* (1976). As in Frith's study, food consisted of seed of native grassland plants most of which were ephemeral or annual herbs belonging to the families Euphorbiaceae, Boraginaceae and Asteraceae. Grasses were relatively unimportant with the exception of the annual grass *Chionachne* sp.; seeds of the dominant cover plants Flinders grass *Iseilema* spp. and Mitchell grass *Astrebla* spp. were not important. The similarity between the results of these studies extends to the relative importance of particular species (e.g. *Trichodesma zeylanicum* and *Wedelia asperrima*). Further, some food plants which differ at the species level may simply have been misidentified in the earlier study. For example, the *Chionachne* species listed in Frith *et al.* (1976) is more likely to have been the common black-soil annual grass *C. hubbardiana* than the tall perennial grass *C. cyathopoda.*

The overall diet was dominated by seed of only four plant taxa, however the relative importance of each varied between samples. In early Dry season 2006 seed of *Wedelia asperrima* comprised 58.9% of the number of seeds, and 53.4% of the dry weight of seed, and declined consistently until the late Wet season. *Phyllanthus lacerosus* displayed a similar pattern. Conversely, *Trichodesma zeylanicum* became more prominent in pooled samples during this period and dominated both the early Wet and late Wet season samples. Seed of *Chionachne hubbardiana* was relatively unimportant until the early Dry season 2007.

Perennial and annual grasses of the genera *Astrebla* and *Iseilema* dominate the standing biomass of Mitchell grass pastures but seed of these species made no significant contribution to the food of Flock Bronzewing Pigeons; rather it is seed of very few species of the inter-tussock community that are critically important. Of 121 taxa recorded in floristic studies, 35 made a contribution to the food, but only six contributed more than 1% of the total dry weight of food.

The differences in dietary patterns between samples probably reflect differences in the availability of seed on the ground surface. Seeds are produced in annual pulses after wet season rainfall but numbers decline during the year due to removal by seed harvesting taxa including ants and birds, burial due to various processes, and ultimately germination. Both *W. asperrima* and *T. zeylanicum* were rarely recorded in floristic descriptions of monitoring plots in 2007, suggesting that germination of these plants was limited in the previous wet season and that most of the seed of these species consumed by Flock Bronzewing Pigeon was a result of seed production following the wet season of 2005/06. *Chionachne hubbardiana* was the only plant of the dominant taxa to have had widespread germination and seed set after a below average wet season in 2006/07.

Dietary patterns within the Wet season months remain poorly described. The post-wet season sample in March 2007 is distinctive due to the presence of species such as *Paspalidium retiglume* (Poaceae) and *Commelina* sp. (Commelinaceae) which were rarely recorded in other samples. Also distinctive is the composition of the contents of the single gizzard collected on 21st April 2006. This limited information suggests that at this time birds select wetter parts of the landscape which may produce seed earlier than other parts of the broad landscape. In short, much more remains to be known of the feeding habits of Flock Bronzewing Pigeons at critical stages of the seasonal cycle, and during the transition from periods of drought to periods of relative seed abundance. There is some evidence from movement data that Flock Bronzewing Pigeons select different parts of the grassland landscape during wet season months, and utilise a different set of resources.

Taxa specific differences in seed dormancy characteristics and seed germination behaviour is clearly an important influence on the dietary patterns of Flock Bronzewing Pigeons. The dormant seed of ephemeral forbs (such as *T. zeylanicum*) may persist for years after seed fall. Consequently, early Wet season rainfall may not result in the rapid depletion of available food by near-simultaneous germination of seed as occurs for graminivorous finches of grassy woodlands of northern Australia (Dostine *et al.* 2001). Flock Bronzewing Pigeons would benefit from the persistence in the landscape of a set of suitable food plants which demonstrate a range of germination tactics and provide seed in a climate of variable rainfall.

The floristic composition of Mitchell grasslands appears to be relatively homogeneous across northern Australia and it might be expected that the dietary patterns observed at the study site are repeated in similar habitats elsewhere. The dominant food species observed in this study are widespread throughout northern Australia including the Barkly Tableland and the northern portion of the Mitchell grass area in Queensland. Flock Bronzewing Pigeons were observed feeding on burnt grassland with abundant fallen seed of *C. hubbardiana* at a site near Burketown on the Gulf Plains in north Queensland in May 2008 (R. Jaensch pers. comm., Figures 7.6 and 7.7). In contrast, the sparse available data from the Channel Country suggests that dietary habits there differ substantially. At Glengyle Station birds were feeding on seeds of plants common during the drying phase of recently flooded depressions. In particular, seed of Common Verbine *Cullen cinereum* was dominant in the food. An anecdotal report from central Queensland suggested that the small seeds of Tick Weed *Cleome viscosa* were taken in large numbers after drought (D. Elliot pers. comm.). The dietary habits of Flock Bronzewing Pigeons in the more intensively developed portions of its range are yet to be examined; dietary differences are expected in accord with differences in the floristic base.

Both *Wedelia asperrima* and *Trichodesma zeylanicum* have been reported as being poisonous. Mortalities in sheep consuming *W. asperrima* have been reported from north-west Queensland; seeds of *T. zeylanicum* caused symptoms of intoxication in ruminants and poultry (Everist 1974). The effects of toxic glycosides and alkaloids from these plants on Flock Bronzewings Pigeons, or on predators of these birds, is unknown. Marshall and Drysdale (1962) note that 'bronzewings' (presumably Common Bronzewing *Phaps chalcoptera*) regularly feed on seeds of the poisonous plant *Gastrolobium* with no ill effects.

The degradation of the interstitial component of perennial grass communities would appear to be an obvious factor in the widespread geographic decline of Flock Bronzewing Pigeons. Even relatively subtle shifts in floristic composition may not be unimportant, but conversion of perennial grasslands to dominance by annual grasses such as Flinders grass *Iseilema* spp. and Button grass *Dactyloctenium radulans*, which has occurred over substantial areas of the range of the Flock Bronzewing Pigeon, would have profound effects on food availability and adverse consequences for this species.

Later chapters in this thesis consider spatial and temporal variation in abundance of the main seed types in the food of Flock Bronzewing Pigeons (Chapter 9), and the effects of grazing on the abundance of food plants (Chapter 11).

7.5 SUMMARY OF FINDINGS AND CONCLUSIONS

The food of Flock Bronzewing Pigeons at a site on the Barkly Tableland in the Northern Territory included the seed of 35 species from 15 plant families. Four annual plant species were dominant in the food: *Wedelia asperrima* (Asteraceae) (43.2% number of seeds, 18.8% dry weight), *Trichodesma zeylanicum* (Boraginaceae) (18.4% number of seeds, 44.4% dry weight), *Chionachne hubbardiana* (Poaceae) (6.2% number of seeds, 20.5% dry weight) and *Phyllanthus lacerosus* (Euphorbiaceae) (26.4% number of seeds, 8.6% dry weight). Seed of perennial grasses including the dominant species within its tussock grassland habitat, Mitchell Grass (*Astrebla* spp.), were not a significant component of the food.

The relative importance of these species varied between samples. Seed of *Wedelia asperrima* comprised >50% of the dry weight of seeds in the mid dry season month of June 2006, but declined over succeeding months to <1% of the dry weight in the late wet season month of March 2007. Conversely, seed of *Trichodesma zeylanicum* comprised 12% of the dry weight of food in June 2006, but comprised >50% of the dry weight of food of the following samples in the late dry season, early wet season and late wet season. Most data presented refer to dietary habits during Dry season months: the foods eaten during the Wet season are less well understood, but there is some evidence of a seasonal shift in diet to include species such as *Commelina tricarinata* (Commelinaceae).

These results match a previous analysis of dietary habits of the species in the region. The principal food plants occur in black-soil habitats throughout northern Australia, and the dietary patterns observed here are probably widespread throughout a large part of their range, though this remains to be tested.

The food of three birds examined from a site in the Channel Country in Queensland was dominated by seed of the herb *Cullen cinereum* (Fabaceae) and the sedge *Schoenoplectus dissachanthus* (Cyperaceae). Both species colonise inundated areas during the drying phase. Both species are widely distributed and occur commonly in northern Mitchell Grass areas, but were not a significant component of the food of Flock Bronzewing Pigeons on the Barkly Tableland.

Figure 7.6 Flock Bronzewing Pigeons and Galahs feeding in burnt grassland near Burketown, Queensland, 27 May 2008.

Photo by R. Jaensch.

Figure 7.7 Seed of *Chionachne hubbardiana* in burnt grassland near Burketown, Queensland.

Photo by R. Jaensch.

Chapter 8: RELATIONSHIP BETWEEN FLORISTICS AND USE OF SITES BY FLOCK BRONZEWING PIGEONS

8.1 INTRODUCTION

The broad association between Flock Bronzewing Pigeons and Mitchell grasslands is widely acknowledged (Frith 1982, McAllan 1996, Higgins and Davies 1996, Garnett and Crowley 2000), although it is known that they are not confined to Mitchell grasslands, and have also been recorded from a range of vegetation types including chenopod shrublands (Williams 1970, Read 1991), dry sedge plains (Crawford 1972), and gibber and sand plains covered with native grasses (Fraser 1990). Most observations of the species coincide with their semi-crepuscular visits to water for drinking; feeding sites are generally remote from drinking sites, and rarely observed or described. Consequently, there are no substantial accounts of their fine-scale habitat preferences within any vegetation type. This study examines the attributes of sites used by Flock Bronzewing Pigeons within Mitchell grasslands, and compares these attributes with those of randomly selected sites in the same landscape. The set of random sites was used for ambient monitoring of seed abundance and floristic composition throughout the study period.

Clues to the foraging site preferences of this species were provided by unquantified observations prior to the commencement of this study. At Pigeon Hole Station in the Victoria River District of the Northern Territory Flock Bronzewing Pigeons were occasionally flushed from the ground from within perceptible patches within the perennial grassland with high densities of seed producing annual forbs and grasses. Further, published dietary studies of pigeons inhabiting Mitchell grasslands (Frith *et al.* 1976) revealed the identity of key food plants and consequently provides some insight into the characteristics of preferred feeding habitat; though curiously Frith *et al.* (1976) suggest that birds were feeding on undigested seed in cattle faeces at watering points, and that results partially reflect the dietary habits of cattle. The dietary habits of this species at this study site are examined in Chapter 7 of this thesis.

A number of approaches to locate and quantify the attributes of foraging sites were considered. Radio-telemetry was deemed to be impractical: the detection range of suitable radio-transmitters was found to be well within the routine home-range movements of pigeons, despite the flat terrain; the precision of position estimates using triangulation methods from fixed stations is unlikely to be sufficient for accurate description of habitat features. Flock Bronzewing Pigeons were rarely encountered on traverses through grasslands on foot or quad-bike, and attempts to follow moving flocks or to locate flocks observed to descend to the ground were usually unproductive. Consequently, the data in this study are drawn primarily from two sources: chance encounters where feeding birds were flushed from the ground within tussock-grassland, and by detection of bird signs including faecal pellets and body feathers. Some data were collected after observation of groups landing on the ground to commence feeding. Flock Bronzewing Pigeons are commonly observed to engage in feeding behaviours on disturbed ground in the near vicinity of watering points (Lindsey 1995), though these are unlikely to be successful. These sites were not considered feeding sites and are not included in this analysis.

8.2 METHODS

8.2.1 Study area

Data were collected primarily on Helen Springs Station (18.434°S 133.874°E) on the Barkly Tableland in the Northern Territory within the period April 2006 to September 2007. Some site data were collected on Eva Downs Station (18.002°S 134.857°E), and on Brunette Downs Station (18.643°S 135.944°E).

8.2.2 Site data

Flock Bronzewing Pigeons are difficult to approach in the field; their presence on the ground in grassland areas is usually signalled only when they flush from the ground at a distance. Nests can be found during breeding by observation of birds as they land in grassland, usually at a distance, and by subsequent searching to flush the bird from the nest site. The presence of breeding activity is associated with aerial display flights in which flying birds adopt an erect winged posture and drop momentarily. There is also an audible distinctive change in the cadence of wing beats. Feeding sites were located by observation of groups of birds either flushing from an area, or landing in an area to commence feeding. Flock Bronzewing Pigeons have a large coiled faecal pellet which is readily observable in the field (Figure 8.1). They are frequently aggregated in groups of 20-30 pellets; their presence plus the presence of pigeon body feathers is a sign of prior use during the dry season.

Figure 8.1 Distinctive grouped faecal pellets of Flock Bronzewing Pigeons.

Data on the attributes of sites used by Flock Bronzewing Pigeons were collected at (i) sites with known nests, (ii) observed feeding sites, and (iii) sites with signs (either or both faecal pellets or feathers) indicating recent use. Data were collected using the same vegetation assessment and seed collection methods as used in studies of floristics and seed dynamics (see Chapter 9). The percent cover of each plant species present was estimated within nine 1 m^2 quadrats positioned in a 3 x 3 grid within a 20 x 20 m plot centred on the bird or bird sign. Cover was estimated using an eight rank scoring system as follows: 0 = none, 1 = 0-1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-95%, 7 = 95-100%. The mean cover per plot for each plant species was derived by averaging the mid-points of these cover ranks. The attributes of sites used by Flock Bronzewing Pigeons were compared with those of the vegetation monitoring sites sampled in each of 2006 and 2007 (see Chapter 9) with no evidence of bird use. Bird signs were detected at several monitoring sites: these were re-classified as bird-use sites. Data from sites sampled in different years were considered to be independent.

At each site, data were collected on the percent cover of all plant species present in quadrats, and on summary variables including percent cover of annual grass, perennial grass, perennial grass basal area, total herbs, total plants, and bare soil. A composite measure of cattle disturbance consisting of scores for cattle hoof prints from 0-3, grazing defoliation from 0-4, and presence of cattle dung from 0-3, was recorded at each site. The biomass of seeds of preferred food plants was determined at each site using methods described in Chapter 9.

8.2.3 Statistical analyses

Multivariate analyses of plant community structure were conducted using PRIMER version 6 (Clarke and Gorley 2006). Data consisted of percent cover estimates of 122 plant taxa at 85 sites. All plant taxa were used in analyses. Percentage cover data were square root transformed prior to analysis. Non-metric multi-dimensional scaling in PRIMER was used to display compositional similarity in two dimensional space, and to display the abundance of key plant species using bubble-plots.

Non-parametric Wilcoxon rank sum tests were used to analyse difference between summary variables, and seed dry weight variables within years. Generalised linear modelling of the probability of occurrence of Flock Bronzewing Pigeons at a site was conducted using the R software package (R Development Core Team 2008), using binomial errors and the logit link function. Modelling of the relationship between floristics and bird presence at a site was conducted in two steps. First, for all 122 plant taxa three models were constructed using the terms (i) % cover of taxon, (ii) % cover of taxon + YEAR, and (iii) % cover of taxon x YEAR. Second, a model set was compiled using taxa with models with percent deviance >20% from step 1, plus other taxa considered to be potential predictor variables including percent cover of *Trichodesma zeylanicum*, *Astebla pectinata* and *A. elymoides*, the disturbance variable 'Cattle index' and the categorical variable 'Year'. The Akaike Information Criterion corrected for sample size (AIC_c) (Burnham and Anderson 2002) was used to assess model support. Further details on model selection are given in section 3.2.7.

8.2.4 Caveats and interpretation

There are a number of caveats which need to be considered in this analysis. Firstly, the data consist solely of observations during dry season months and provide no information on habitat use during wet season months. Results from other studies (e.g. Chapter 7) suggest that habitat and resource requirements vary seasonally. Secondly, some observations are spatially clustered and consequently results may reflect the attributes of relatively few identified sites rather than be representative of the full spectrum of feeding or nesting sites in the study area. Thirdly, it was assumed that sites with evidence of bird presence were feeding sites, though this cannot be substantiated. Indeed, sites identified by detection of bird signs may be used for a variety of different purposes including feeding, resting during the day, or roosting at night. Each may have subtly different habitat characteristics. There was no attempt to discriminate between nesting and feeding habitat in these analyses. The small sample size of nesting sites precludes separate analysis: birds were occasionally observed feeding in similar habitat and data has been pooled. Lastly, the data may be biased by the fact that observations are invariably restricted to the proximity of vehicle tracks. Cattle use tracks to move between feeding and watering areas, and the near vicinity of tracks may be relatively more disturbed than parts of the landscape distant from tracks.

8.3 RESULTS

Habitat data were collected at 22 sites including four nest sites, eight feeding sites and ten sites with bird signs (Table 8.1). Twenty sites were located on Helen Springs Station, and single sites on Eva Downs Station and Brunette Downs Station. Twelve sites were located and described in 2006; ten sites were located and described in 2007. All nests were situated on the ground sheltered by the decumbent stems of the perennial tussock-grass *Astrebla elymoides* (Figures 8.2 and 8.3), and were located less than 1 km from water in areas with moderate disturbance from grazing cattle. Three of four nests were located in late August 2006, near the end of a breeding season which had commenced by April 2006. Flock Bronzewing Pigeons were observed to feed in structurally varied micro-habitats within Mitchell grasslands including pea-bush swamps with the erect annual herb *Sesbania brachycarpa*, relatively open herb-fields with sparse tussocks of *Astrebla elymoides*, as well as relatively dense tussock grasslands with *Astrebla elymoides* and *A. pectinata*.

Table 8.1 Types of habitat sites, date and geographic coordinates of sites.

HS Helen Springs Station, ED Eva Downs Station, BD Brunette Downs Station.

Type	Date	Station	Latitude (°S)	Longitude (°E)
Feed	18-Apr-07	HS	18.0106	134.4361
Feed	23-Aug-06	HS	18.0414	134.4087
Feed	24-May-07	HS	18.0131	134.4468
Feed	25-May-07	HS	18.0121	134.4465
Feed	25-May-07	HS	18.0128	134.4471
Feed	30-May-07	HS	18.0130	134.4494
Feed	30-May-07	HS	18.0126	134.4489
Feed	23-Apr-06	BD	18.5701	136.0245
Pellet	25-Sep-06	ED	18.1259	134.5324
Pellet	30-May-07	HS	18.0420	134.4067
Pellet	Dec-06	HS	18.3418	134.3739
Pellet	30-May-07	HS	18.0422	134.4068
Pellet	19-Apr-07	HS	18.3468	134.4035
Pellet	30-May-07	HS	18.0420	134.4066
Pellet	Sep-06	HS	18.2268	134.4028
Pellet	Sep-06	HS	18.3443	134.4106
Pellet	Dec-06	HS	18.3422	134.3637
Pellet	Sep-06	HS	18.0844	134.2622
Nest	18-May-06	HS	18.3475	134.3411
Nest	26-Aug-06	HS	18.0406	134.4079
Nest	26-Aug-06	HS	18.0403	134.4078
Nest	28-Aug-06	HS	18.0413	134.4086

Figure 8.2 Nesting habitat of Flock Bronzewing Pigeons.

Black-soil plain with mixed annual forbs and sparse tussocks of *Astrebla elymoides*, 28th August 2006. Nest positioned under tussock in centre foreground.

Figure 8.3 Nest of Flock Bronzewing Pigeon.

Nest under tussock of *Astrebla elymoides*, 29th August 2006.

8.3.1 Multivariate analyses

Sites used by Flock Bronzewing Pigeons clustered in MDS ordination space (Figure 8.4). Bubble-plots of the abundance of the perennial grasses *Astrebla pectinata* and *A. elymoides* superimposed on the plot of the MDS ordination based on square-root transformed data suggests occupation of different parts of the ordination space. *A. elymoides* and *C. hubbardiana* are abundant in the region occupied by Flock Bronzewing Pigeon habitat sites.

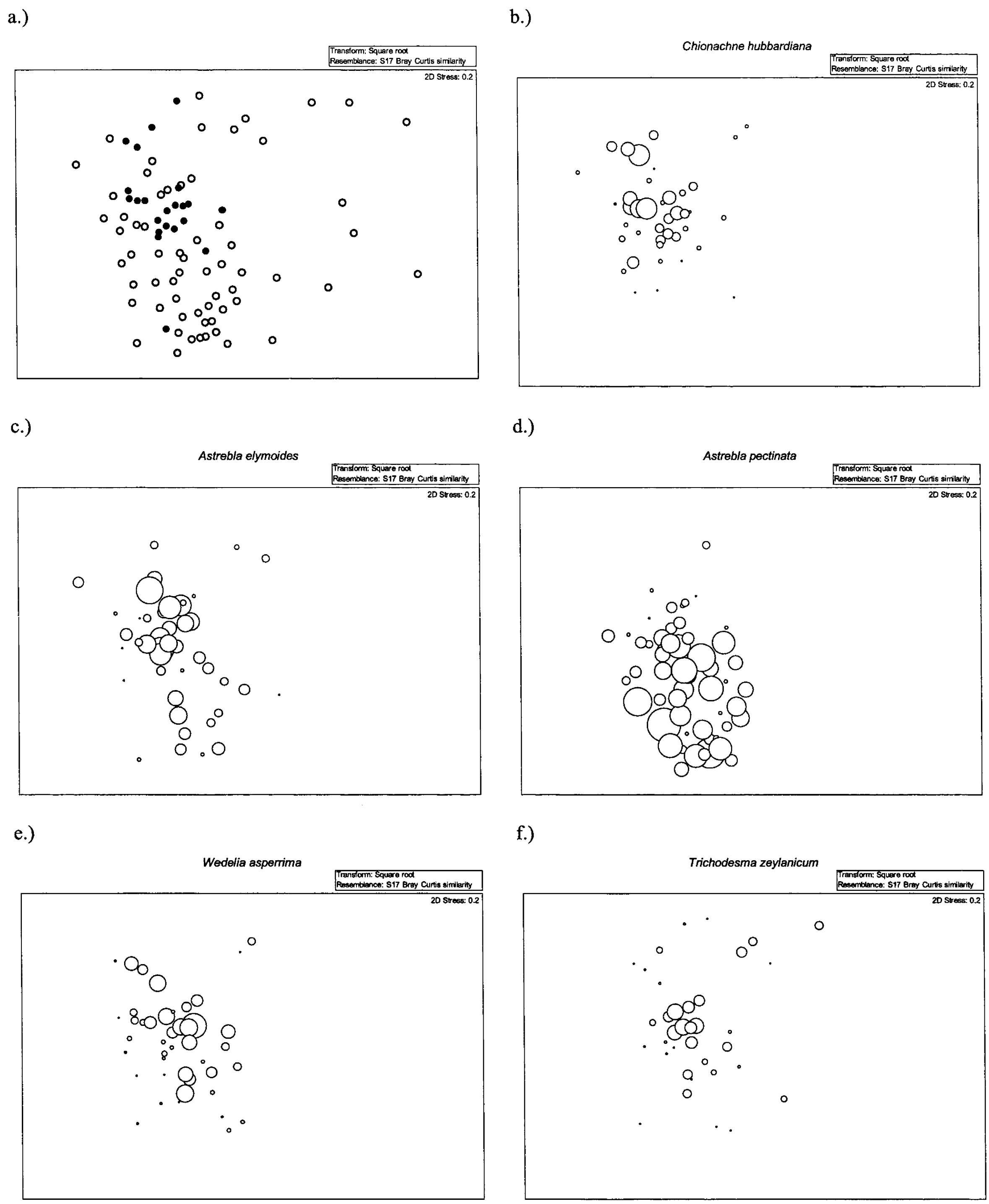


Figure 8.4 MDS ordination of plant communities at used and unused sites.

a.) MDS ordination based on plant species composition showing sites occupied by Flock Bronzewing Pigeons (solid symbols) and unoccupied sites (hollow symbols). Bubble-plots of abundance of b.) *Chionachne hubbardiana*, c.) *Astrebla elymoides*, d.) *Astrebla pectinata*, e.) *Wedelia asperrima*, and f.) *Trichodesma zeylanicum*.

8.3.2 Univariate analyses

Non-parametric Wilcoxon rank sum tests identified differences in attributes of used and unused sites within years. There were significant differences in the variable 'Cattle index' in year 1 and significant differences in 6 of 10 tests using seed dry weight variables (Table 8.2). In each case the mean dry weight of seed was greater at used sites than unused sites. Binomial modelling of these variables (excluding seed dry weight variables) failed to yield any model distinguishable from the null model (Table 8.3).

Table 8.2 Results of Wilcoxon rank sum tests for non-parametric comparison of variables between years.

Variable	Pres. 2006	Abs. 2006	P value	Pres. 2007	Abs. 2007	P value
% cover annual grass	15.7	16.6	0.557	8.7	13.3	0.370
% cover herbs	24.1	24.8	0.731	16	16.4	1.000
% basal area perennial grass	2.8	3.9	0.473	6.8	6.0	0.911
% cover perennial grass	6.2	8.4	0.538	13.3	12.7	0.877
% cover bare soil	44.7	35.8	0.178	54.9	48.9	0.604
% total plant cover	49.8	57.7	0.223	42.5	44.9	0.922
Cattle index	1.0	0.6	0.049	1.5	1.4	0.317
Plant richness	26.7	26.5	0.908	25.2	22.1	0.101
Dry wt *Chionachne* seed	1,643	192	0.336	244	171	0.014
Dry wt *Phyllanthus* seed	88	53	0.252	18	23	0.768
Dry wt *Trichodesma* seed	892	845	0.284	793	269	0.003
Dry wt *Wedelia* seed	780	351	0.003	270	110	0.010
Dry wt four spp. combined	3,403	1,442	0.018	1,325	617	0.006

Table 8.3 Results of binomial modelling of site attributes and probability of occurrence of Flock Bronzewing Pigeons.

Model	Log likelihood	k	AICc	d.AICc	wi	pcdev
Null model	-48.60	2	101.36	0.00	0.122	0.0
plant_rich	-47.55	3	101.40	0.04	0.119	2.2
soil_cov	-47.77	3	101.84	0.49	0.095	1.7
tot_cov	-48.14	3	102.59	1.23	0.066	0.9
soil_cov+YEAR	-47.11	4	102.72	1.36	0.062	3.1
cattle_index	-48.40	3	103.09	1.73	0.051	0.4
ann_gr_cov	-48.40	3	103.11	1.75	0.051	0.4
pg_cov	-48.47	3	103.23	1.88	0.048	0.3
pg_bac_cov	-48.56	3	103.41	2.05	0.044	0.1
herb_cov	-48.60	3	103.50	2.15	0.042	0.0
plant_rich+YEAR	-47.53	4	103.56	2.20	0.040	2.2
tot_cov+YEAR	-47.59	4	103.68	2.32	0.038	2.1
cattle_index*YEAR	-46.83	5	104.43	3.07	0.026	3.6
cattle_index+YEAR	-47.97	4	104.44	3.08	0.026	1.3
soil_cov*YEAR	-46.94	5	104.64	3.29	0.024	3.4
ann_gr_cov+YEAR	-48.10	4	104.70	3.34	0.023	1.0
plant_rich*YEAR	-47.12	5	104.99	3.64	0.020	3.1
pg_cov+YEAR	-48.30	4	105.10	3.75	0.019	0.6
tot_cov*YEAR	-47.18	5	105.12	3.77	0.018	2.9
herb_cov+YEAR	-48.35	4	105.20	3.84	0.018	0.5
pg_bac_cov+YEAR	-48.36	4	105.22	3.86	0.018	0.5
ann_gr_cov*YEAR	-47.79	5	106.33	4.98	0.010	1.7
pg_bac_cov*YEAR	-47.95	5	106.65	5.30	0.009	1.4
pg_cov*YEAR	-47.99	5	106.74	5.39	0.008	1.3
herb_cov*YEAR	-48.34	5	107.45	6.09	0.006	0.5

Binomial modelling of 122 plant taxa yielded models which explained >20% of the model deviance for three taxa: *Chionachne hubbardiana*, *Wedelia asperrima* and *Goodenia strangfordii*. All are annual or ephemeral herbs; both *C. hubbardiana* and *W. asperrima* have been identified as significant food plants for the Flock Bronzewing Pigeon. Analysis of the model set listed in Table 8.4 yielded a preferred model with 45.4% explained deviance (Table 8.5), in which C. *hubbardiana* and *W. asperrima* were significant terms (Table 8.6). The remaining terms including '% cover of *Goodenia strangfordii*', '% cover of *Astrebla elymoides*' and '% cover of *Trichodesma zeylanicum*' were non-significant, though '% cover of *A. elymoides*' approached significance at the 0.05 level.

Table 8.4 Model set used for modelling probability of occurrence of Flock Bronzewing Pigeons.

Ch_hub = % cover of *Chionachne hubbardiana*, We_asp = % cover of *Wedelia asperrima*, Go_str = % cover of *Goodenia strangfordii*, Tr_zey = % cover *of Trichodesma zeylanicum*, As_pec = % cover of *Astrebla pectinata*, As_ely = % cover of *Astrebla elymoides*

Model
Present ~ 1
Present ~ Ch_hub
Present ~ We_asp
Present ~ Go_str
Present ~ Tr_zey
Present ~ Ch_hub + YEAR
Present ~ We_asp + YEAR
Present ~ Go_str + YEAR
Present ~ Tr_zey + YEAR
Present ~ Ch_hub + cattle_index + YEAR
Present ~ We_asp + cattle_index + YEAR
Present ~ Go_str + cattle_index + YEAR
Present ~ Tr_zey + cattle_index + YEAR
Present ~ Ch_hub + As_pec + cattle_index + YEAR
Present ~ We_asp + As_pec + cattle_index + YEAR
Present ~ Go_str + As_pec + cattle_index + YEAR
Present ~ Tr_zey + As_pec + cattle_index + YEAR
Present ~ Ch_hub + As_ely + cattle_index + YEAR
Present ~ We_asp + As_ely + cattle_index + YEAR
Present ~ Go_str + As_ely + cattle_index + YEAR
Present ~ Tr_zey + As_ely + cattle_index + YEAR
Present ~ Ch_hub + We_asp + Go_str + Tr_zey +As_ely
Present ~ Ch_hub + We_asp + Go_str + Tr_zey +As_pec

Table 8.5 Results of generalised linear modelling of probability of occurrence of Flock Bronzewing Pigeons and habitat attributes at 85 sites.

Model	Log likelihood	k	AICc	d.AICc	wi	pcdev
Ch_hub+We_asp+Go_str+Tr_zey+As_ely	-26.52	7	68.49	0.00	0.745	45.4
Ch_hub+We_asp+Go_str+Tr_zey+As_pec	-28.16	7	71.77	3.28	0.145	42.1
Ch_hub	-33.81	3	73.91	5.42	0.050	30.4
Ch_hub+As_ely+Cattle_index+YEAR	-30.92	6	74.91	6.42	0.030	36.4
Ch_hub+YEAR	-33.78	4	76.05	7.56	0.017	30.5
Ch_hub+Cattle_index +YEAR	-33.57	5	77.90	9.40	0.007	30.9
Ch_hub+As_pec+Cattle_index+YEAR	-33.43	6	79.93	11.44	0.002	31.2
Go_str+As_ely+Cattle_index+YEAR	-33.69	6	80.46	11.96	0.002	30.7
Go_str+YEAR	-36.27	4	81.04	12.54	0.001	25.4
Go_str+Cattle_index+YEAR	-36.21	5	83.17	14.68	0.000	25.5
Go_str	-38.96	3	84.21	15.72	0.000	19.8
Go_str+As_pec+Cattle_index+YEAR	-36.21	6	85.49	16.99	0.000	25.5
We_asp+As_ely+Cattle_index+YEAR	-39.48	6	92.05	23.55	0.000	18.8
We_asp	-43.29	3	92.88	24.38	0.000	10.9
We_asp+YEAR	-42.61	4	93.73	25.23	0.000	12.3
We_asp+Cattle_index+YEAR	-42.19	5	95.13	26.64	0.000	13.2
We_asp+As_pec+Cattle_index+YEAR	-42.02	6	97.11	28.61	0.000	13.6
Tr_zey	-46.33	3	98.96	30.46	0.000	4.7
Tr_zey+As_ely+Cattle_index+YEAR	-43.55	6	100.18	31.69	0.000	10.4
Tr_zey+YEAR	-46.25	4	101.01	32.51	0.000	4.8
Null model	-48.60	2	101.36	32.86	0.000	0.0
Tr_zey+Cattle_index+YEAR	-45.86	5	102.48	33.98	0.000	5.7
Tr_zey+As_pec+Cattle_index+YEAR	-45.72	6	104.51	36.01	0.000	5.9

Table 8.6 Model parameters of preferred model of probability of occurrence of Flock Bronzewing Pigeons and habitat attributes at 85 sites.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-3.044	0.585	-5.20	0.0000	***
Ch_hub	0.575	0.276	2.08	0.0373	*
We_asp	0.315	0.134	2.35	0.0186	*
Go_str	0.249	0.166	1.50	0.1332	ns
Tr_zey	-0.163	0.221	-0.74	0.4600	ns
As_ely	0.118	0.064	1.84	0.0651	ns

8.4 DISCUSSION

The results of this study are congruent with published studies on the diet of this species (Frith *et al.* 1976), and results presented elsewhere in this thesis (Chapter 7). This study yielded evidence that Flock Bronzewing Pigeons favour grassland sites with high abundances of preferred food plants, particularly the annual grass *Chionachne hubbardiana* and the annual forb *Wedelia asperrima.* Multivariate and univariate analyses of habitat selection by Flock Bronzewing Pigeons consistently revealed associations between the presence of Flock

Bronzewing Pigeons and the abundance of seed of preferred food plants, and cover of preferred food plants, particularly the annual grass *Chionachne hubbardiana.* Seed of this species comprised 20.5% of the total dry weight of food of pigeons collected during this study, and similarly 16% of the volume of food in the study of Frith *et al.* (1976); there is also anecdotal evidence (see Figures 7.6 and 7.7, Chapter 7) that it may be a significant food type for these and other granivorous birds throughout northern Australia. On the basis of scant field observations in western New South Wales, and interpretation of the historical literature, McAllan (1996) proposed that the perennial tussock-grass *Panicum decompositum* was a significant food plant and therefore habitat plant for Flock Bronzewing Pigeons. These results provide little support for this hypothesis, though *P. decompositum* may be important in other parts of their range.

Typical feeding sites of Flock Bronzewing Pigeons feature perennial tussock-grasses including *A. elymoides* and *A. pectinata* on raised pedestals within a network of inter-tussock channels containing a diverse community of annual and ephemeral forbs (Figures 8.5). The effect of grazing pressure on these specific communities has not been examined, though the prominence of species with weedy characteristics such as *Sida spinosa* and *Wedelia asperima* suggests that these communities are tolerant of grazing, if not maintained by moderate levels of grazing; and that preferred habitat may be moderately degraded patches of grassland dominated by *A. elymoides*. Results presented elsewhere in this thesis (Chapter 11), based on analysis of data from landscape-scale grazing trials, suggest that the food plants *Wedelia asperrima* and *Trichodesma zeylanicum* persist in grazed landscapes, and may be favoured by high grazing pressure, though the evidence for unambiguous grazing effects is weak.

This study used plot-based compositional data. There was no explicit attempt to examine spatial or structural aspects of habitat selection at any scale. This may be important given that field observations suggest a preference for open patches in the grassland with higher abundances of annual forbs and grasses. Whether theses patches are due to edaphic variation in grasslands or are a consequence of grazing by cattle is not known.

The annual grass *C. hubbardiana* is suspected to be a key species for Flock Bronzewing Pigeons in the northern part of their range, and as such warrants further attention. As a palatable and large-seeded annual grass it may be vulnerable to local extinction through grazing pressure, and information on its distribution across grazing gradients at local and regional scales should be sought. Data from the few existing studies on grazing impacts in Mitchell grasslands shed little light on the grazing sensitivities of this species (Fisher 2001).

8.5 SUMMARY OF FINDINGS AND CONCLUSIONS

Predictors of site use by Flock Bronzewing Pigeons were examined on black-soil plains dominated by perennial tussock-grasses on the Barkly Tableland in the Northern Territory. Habitat attributes included measures of abundance of plant species within 20 x 20 m plots. Data were collected at 22 sites with direct or indirect evidence of bird use, and 63 ambient non-bird sites within the period April 2006 to September 2007.

Ordination of plant community composition data of used and unused sites revealed that used sites cluster within ordination space. Bubble-plots of the abundance of plant taxa suggest that the food plants *Chionachne hubbbardiana*, *Wedelia asperrima* and *Trichodesma zeylanicum* occupy similar parts of the ordination space. This pattern is shared by the perennial tussock-grass Hoop Mitchell Grass *Astrebla elymoides*, but not by the dominant Barley Mitchell Grass *A. pectinata*.

Non-parametric tests of attribute differences between used and unused sites within years consistently identified significant differences in dry weight of seed of food plants. Other variables were not significant with the exception of a measure of disturbance by cattle in 2006. Binomial modelling revealed no evidence of relationships between pigeon presence and eight summary variables.

Binomial modelling of the relationship between presence of Flock Bronzewing Pigeons at a site and percentage cover of individual plant taxa yielded evidence of an association between use of a site and the abundance of the food plants *C. hubbardiana* and *W. asperrima*. The best supported model explained 45.4% of the model deviance and included percentage cover of *C. hubbardiana, W. asperrima* and *Astrebla elymoides*. These species may constitute useful markers of habitat quality for Flock Bronzewing Pigeons in Mitchell grasslands of northern Australia.

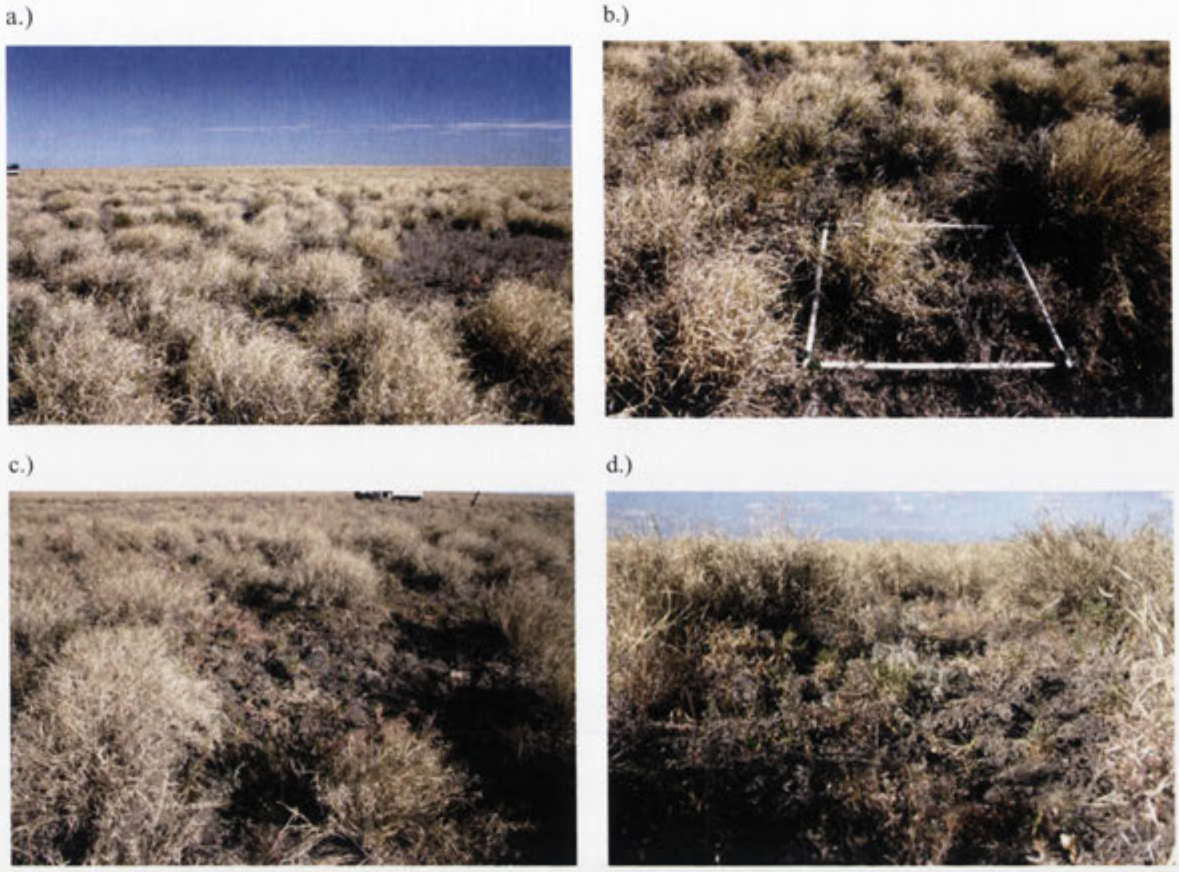


Figure 8.5 Feeding habitat of Flock Bronzewing Pigeons.

a.) Feeding habitat with co-dominant perennial tussock grasses *Astrebla elymoides* and *A. pectinata*, b.) Feeding site showing 1m^2 sampling quadrat, c.) Feeding site in *Astrebla* grassland on Helen Springs Station, d.) Ground view of plant community in inter-tussock channels.

Chapter 9: PATTERNS OF RESOURCE AVAILABILITY. FROM SATELLITES TO SEEDS

9.1 INTRODUCTION

The ecological implications of pulses of precipitation on plant productivity and resources for vertebrate consumers in arid and semi-arid ecosystems have been well described (Holmgren *et al.* 2006, Dickman *et al.* 1999, Letnic and Dickman 2006). For granivorous organisms such as rodents and seed-eating birds, pulses of precipitation provide an ephemeral increase in seed resources which underpin breeding and population increases (Dickman *et al.* 1999, Zann *et al.* 1995). Variation in resource levels is rarely measured directly, and there are few long-term studies that cover periods of extended rainfall and drought (Gutierrez *et al.* 2000). This study reports results of measurements of plant community composition and soil seed density at sites in Mitchell grasslands in two years with contrasting patterns of prior rainfall.

Mitchell grass communities are composed of perennial tussock-grasses and a diverse interstitial community of annual grasses and annual or perennial forbs. Studies on the temporal dynamics of Mitchell grasslands are mostly confined to the perennial tussock-grasses (Orr *et al.* 1986, Orr 1991, Orr and Evenson 1991, Orr and Phelps 1994,). Whilst there are quantitative studies on compositional change which include parts of the non-perennial grass component (Orr 1981, Hall 1982, Foran and Bastin 1984, Ford 1992), few attempt to address the entire assemblage, and there are none for the Barkly Tableland in the Northern Territory. Orr (1981) found an inverse relationship between the abundance of perennial grass and forbs over an eight year period at sites in southern Queensland. Botanical composition is mediated by the competitive ability of perennial grasses. The basal area of perennial grasses is reduced by mortality during periods of below average rainfall, and increased by vegetative growth during favourable periods. Orr concluded that the relative abundance of perennial grasses is determined by recent rainfall history (1-3 years) while the relative abundance of annual grasses and forbs is determined by the timing of immediate past rainfall. Understanding temporal patterning consequently demands long-term monitoring to capture the range of climatic variation. Estimates of the number of years required vary (Taylor and Tulloch 1985, Phelps *et al.* 1993, Jones *et al.* 1995), but on the Barkly Tableland may be of the order of ten years or more with the inclusion of periodic major climatic events, and certainly beyond the scope of this study.

The dynamics of seed soil density in black-soil grasslands of northern Australia have largely been ignored, except in studies of germination and recruitment of the dominant perennial grass *Astrebla* spp. in these grasslands (Orr 1991). This study focussed on the abundance of seed of four food plants identified in previous studies (Chapter 7). The food of Flock Bronzewing Pigeons includes seed of 35 plant species, but four plant species comprised over ninety percent of the number and dry weight of the combined food. These species are *Chionachne hubbardiana* (Poaceae), *Phyllanthus lacerosus* (Euphorbiaceae), *Trichodesma zeylanicum* (Boraginaceae) and *Wedelia asperrima* (Asteraceae). This chapter addresses the following questions:

(1) Does the abundance of known food plant species of the Flock Bronzewing Pigeon vary between floristic groups in Mitchell grasslands and between years of contrasting rainfall?

(2) Does the abundance of seed of these species vary between floristic groups and between years?

(3) Are there differences between species in the percentage of whole seeds in the seed bank?

(4) What are the implications for granivorous birds such as Flock Bronzewing Pigeons?

9.2 METHODS

9.2.1 Study area

The study was conducted on Helen Springs Station (18.434°S 133.874°) in the western Barkly region of the Northern Territory. Helen Springs Station lies predominantly to the east of the Stuart Highway and extends north to overlap the Barkly Stock Route. The station homestead is approximately 140 km north north-west from the township of Tennant Creek. Rainfall is highly seasonal, with a summer wet season from November to April and a dry season from May to October. Average seasonal rainfall (July-June) is 449 mm, based on 63 years of records. The minimum recorded seasonal rainfall total is 63 mm in 1951/52; the maximum recorded seasonal rainfall total was 1,325 mm in 2000/01. Relevant to the period of this study, seasonal rainfall totals were 120 mm in 2004/05, 862 mm in 2005/06, and 474 mm in 2006/07; the percentage ranks of seasonal rainfall totals were 4.5%, 93.5% and 62.9% respectively.

The land resources of Helen Springs Station have been mapped using interpretation of aerial photography by Grant (2003). Mapping was based on delineation of 36 land units, each with consistent landform, soil and vegetation characteristics. Land units were classified into eight groups broadly distributed across an elevational gradient from hilly terrain to alluvial plains with cracking clays, to drainage floors, floodplains and floodouts, to chenopod swamps. Two land unit groups predominantly comprise Mitchell grass plains or 'downs country' (land unit groups 4 and 5). These groups are interspersed throughout the black soil plains (Figure 9.1), and each comprises several individual land units based on classification of landform, soil and vegetation attributes (Table 9.1). This study did not sample across the full elevational gradient but focussed on land units within the downs country as these comprise the principal habitat of Flock Bronzewing Pigeons. Site selection was based on desktop analysis of the land unit map of Helen Springs Station. Most sites were selected from the dominant classes of Mitchell grass habitat i.e. land units 4.2, 5.1, 5.2, and 5.3 using criteria of proximity to station roads and a minimum distance from bores of 1 km. Additional sites were positioned along drainage lines and in chenopod swampland.

Table 9.1 Description of 'downs country' land units, and % total area and % combined area of land unit groups 4 and 5.

Land unit descriptions and data from Grant (2003).

Land unit	Land unit description	% total area	% area 'downs'
4.1	Gravelly gilgaied plains with annual grasses and Silky Browntop *Eulalia aurea* in gilgais	4.2	8.2
4.2	Gilgaied plains with Barley Mitchell grass *Astrebla pectinata* and Ribbon grass *Chrysopogon fallax*	12.2	24.0
4.3	Plains with linear Gilgai	4.1	8.1
5.1	Plains with Barley Mitchell grass *A. pectinata*	12.0	23.7
5.2	Plains with annual grasses	7.0	13.8
5.3	Plains with Barley Mitchell grass *A. pectinata* and Hoop Mitchell grass *A. elymoides*	8.5	16.8
5.4	Plains and drainage floors with Silky Browntop *E. aurea*	0.9	1.7
5.5	Floodouts and floodplains with Mitchell grasses	1.9	3.7

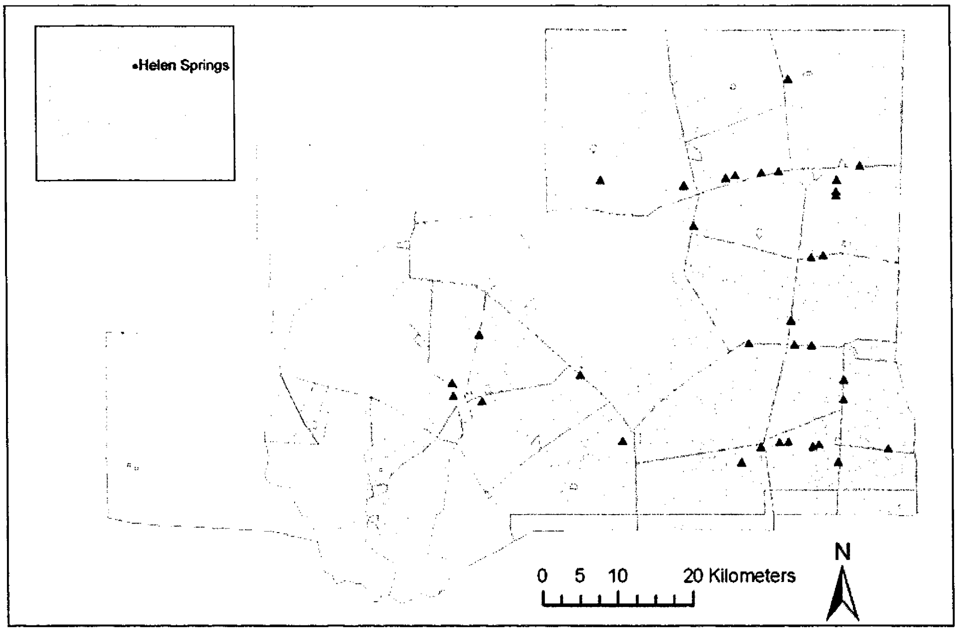


Figure 9.1 Distribution of 35 sampling plots, and distribution of combined 'downs country' land units on Helen Springs Station, Northern Territory.

Inset: Location of Helen Springs Station.

9.2.2 Patterns of plant productivity

Estimates of gross primary productivity (GPP mmol CO_2 m^{-2} day^{-1}) of the raingreen component of vegetation were derived from MODIS satellite imagery processed and provided by Dr S. Berry of the Fenner School of Environment and Society at the Australian National University. Methods of data acquisition and analysis are presented by Berry *et al.* (2007). Data for GPP at coordinates of 35 vegetation monitoring plots were extracted from digital grids for each month from July 2000 to June 2007 using ArcGIS (ESRI 2004).

GPP data are presented as average values of 35 points, and as standardised GPP values (*Z*-scores) to determine deviation of GPP relative to the mean-monthly values (Barbosa *et al.* 2006). Monthly standardized GPP values were calculated using $Z = [(GPP(x,y)i,j - MEAN\ GPP(x,y)i,j)/SD\ GPP(x,y)i,j]$, which measures the *Z* scores of GPP at points in space (x = longitude, y = latitude) and time (i = month, j = year), where GPP(x,y)i,j represents the spatially averaged GPP value over 35 points in a given month, MEAN GPP(x,y)i,j the spatially averaged GPP value for that month over all years, and SD GPP (x,y)i,j the standard deviation of GPP values for a given month in each year. The base period of eight years is barely long enough to reflect long-term average conditions.

9.2.3 Plant community dynamics

Thirty five sites were sampled for floristic composition in the early Dry season of 2006 and 2007 after the cessation of wet season rainfall. In 2006 sites were assessed between 9-29 June, after a cyclone in late April delivered heavy rainfall to the region, and in 2007 sites were assessed between 18-23 April. At this time in the early Dry season most plants have completed flowering and seeding and hence able to be identified, and the ephemeral component is still present. The cover of each plant species present was estimated within nine 1 m^2 quadrats positioned in a 3 x 3 grid within a 20 x 20 m plot. Cover was estimated using an eight rank scoring system as follows: 0 = none, 1 = 0-1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-95%, 7 =95-100%. The mean cover per plot for each plant species was derived by averaging the mid-points of these cover ranks. Plant cover estimates for each species per quadrat were averaged to derive an average cover estimate for each species per site. Plants were identified with the assistance of a reference field herbarium, and with the assistance of staff from the Northern Territory Herbarium. Some species pairs presented identification difficulties. *Phyllanthus maderaspatensis* and *P. lacerosus* can be difficult to distinguish in the field, though the seed is distinctive (Hunter and Bruhl 1997). The distinction is maintained in this data. *Iseilema vaginiflorum* and *I. macratherum* were not distinguished and are referred to as *I. vaginiflorum*. A small number of genera including *Commelina*, *Boerhavia* and *Polygala* were not identified to species. For each quadrat additional data were collected using the same cover ranks for shrubs > 1m in height, shrubs < 1m in height, total perennial grasses, basal area of perennial grasses, total annual grasses, total herbs, total plant cover, bare soil and plant litter. For each quadrat data were collected on cattle disturbance indices as follows: cattle hoof prints scored from 0-3, grazing defoliation scored from 0-4, and presence of cattle dung scored from 0-3. The index is a composite score with a possible maximum of 10. On most occasions a photograph of the plot was taken in the same direction from the mid-point of the plot (Figure 9.2).

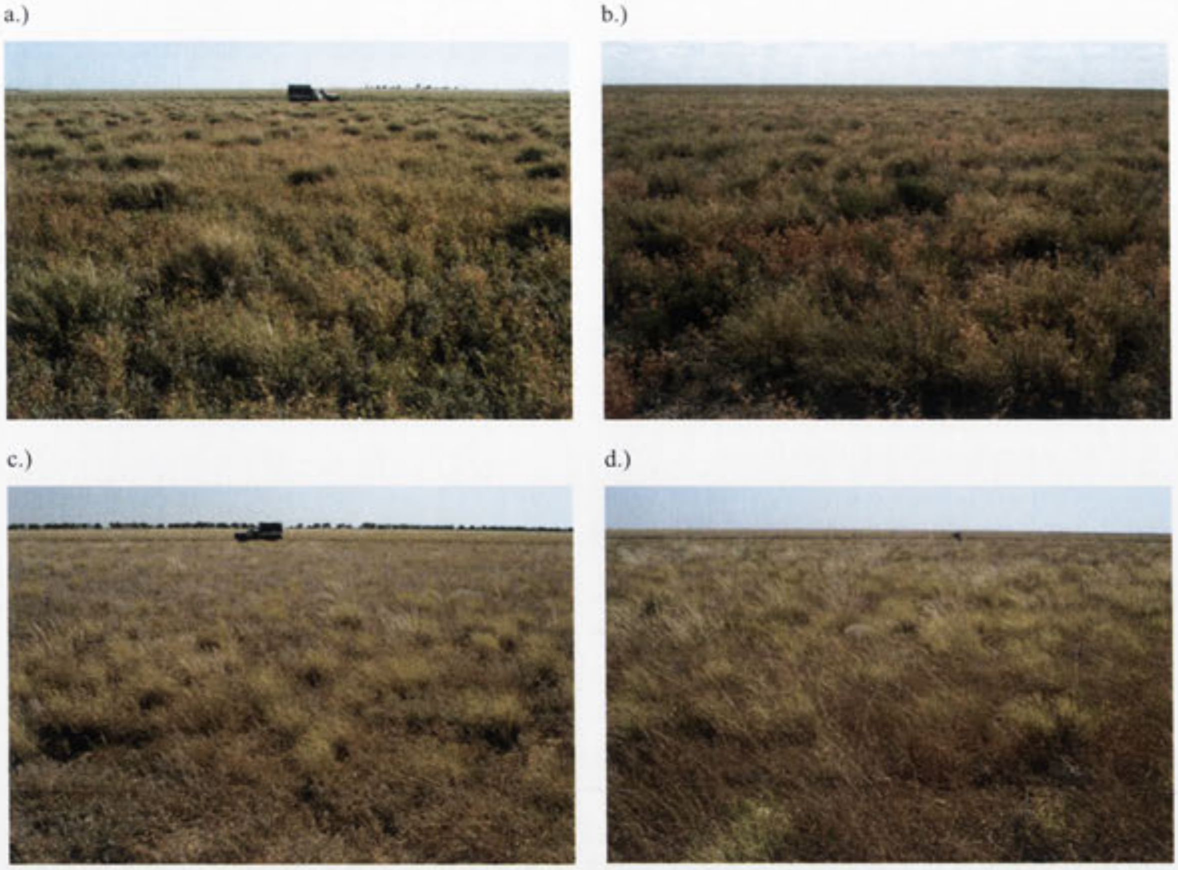


Figure 9.2 Floristic survey plots, Helen Springs Station, April 2007.

a.) Plot number 23, b.) plot number 31, c.) plot number 2, d.) plot number 5.

9.2.3.1 Statistical analyses

Multivariate analyses were conducted using the software program PRIMER version 6 (Clarke and Gorley 2006). Data were square root transformed prior to analysis. This is a moderate data transformation to give additional weight to species of intermediate abundance (Clarke and Warwick 1994). The Bray-Curtis dissimilarity measure was used to calculate similarity of compositional structure between sites. This is a commonly used measure recommended for ecological analyses (Faith *et al*. 1987). Compositional similarity between sites was analysed within years using the classification procedure CLUSTER. The procedure SIMPER was used to identify those species discriminating between groups identified by classification procedures. Non-metric multi-dimensional scaling (MDS) ordination was used to display the compositional similarity of sites in each of two years. The abundance of food plants including *Chionachne hubbardiana*, *Wedelia asperrima*. *Trichodesma zeylanicum* and *Cullen cinereum* are displayed as bubble-plots in ordinations for each year. Similarly, the abundance of dominant perennial tussock-grasses including *Astrebla elymoides*, *A. pectinata*, *Chrysopogon fallax* and *Aristida latifolia* are displayed as bubble-plots. Finally, the combined dry weight of seeds (mg/m^2) per plot of four principal food plants of Flock Bronzewing Pigeons (*C.*

hubbardiana, *W. asperrima*, *T. zeylanicum* and *P. lacerosus*) are displayed as bubble-plots (seed sampling methods described in 9.2.4).

Differences in plant community structure between years were analysed using the ANOSIM procedure and the one-way routine. This test operates on the underlying resemblance matrix and calculates an average of all pair-wise correlations between the among site resemblance matrices for each time and compares the statistic with data derived from random permutations of site labels to obtain a null permutation distribution and thus a significance test (Clarke and Gorley 2006). The ANOSIM test for differences between years was conducted using average cover data and presence/absence data. The SIMPER procedure was used to identify taxa contributing to 50% of the cumulative average dissimilarity and which discriminate between groups (in this case, Years). This procedure calculates the relative contribution of individual taxa to the overall average dissimilarity between groups i.e. average of pairwise dissimilarities between group members; and provides a measure to identify taxa discriminating between groups, based on the ratio of the average contribution to dissimilarities and the standard deviation of the dissimilarity values (Clarke and Warwick 1994). Taxa which contribute to 50% of the cumulative average dissimilarity are listed. Analyses were conducted on both average cover data and presence/absence data.

Univariate statistical analyses were conducted using the R software package (R Development Core Team 2008). Inter-annual differences in the frequency of occurrence of species was analysed at the site scale. Analyses were confined to 41 taxa present in at least 10 of 35 sites in either year. Probability of occurrence was modelled using binomial errors and the logit link function, with Year as a categorical variable. The Akaike Information Criterion corrected for small sample size (AIC_c) was used to discriminate the Year model from the null model. Where data are over-dispersed the quasi-AIC_c ($QAIC_c$) was calculated using the formula of Burnham and Anderson (2002). Further details on model selection are given in section 3.2.7.

Paired sample t-tests were used to test inter-annual differences between site variables including plant species richness, annual grass cover, herb cover, perennial grass basal area cover, perennial grass cover, soil cover, total plant cover and cattle index. Values of differences between paired samples were tested for normality with the Shapiro-Wilks normality test; where differences were not normally distributed the non-parametric Wilcoxon paired-sample test was used. Cover estimates were arcsine transformed prior to analysis.

9.2.4 Seed dynamics

9.2.4.1 Sample collection and processing

Seed abundance in each of 35 20 x 20 m plots was measured on six occasions at three–monthly intervals from June 2006 to September 2007. Seed abundance was measured by collecting surface soil and seeds within ten randomly placed 25 x 25 cm quadrats using a coarse brush and a collecting pan. The ten samples from each plot were pooled and stored in a plastic geological sample bag and stored in the dark at ambient temperatures. At the laboratory samples were rinsed on two nested metal sieves of 425 mm diameter and 0.8 mm and 8 mm mesh size, to remove the fine soil fraction. The coarse material retained on the top sieve was discarded, the retained fraction on the 0.8 mm sieve dried in a drying oven at 60 °C for at least 24 hours and stored in a plastic geological sample bag. This process did not eject seed of the targetted species.

Figure 9.3 Geo-splitter used for sub-sampling of soil samples for analysis of seed abundance from floristic plots on Helen Springs Station.

9.2.4.2 Seed enumeration

The dried sample was divided into equal fractions using a geo-splitter (Figure 9.3), and seeds in one randomly selected half of the sample were sorted using a channelled white plastic tray and a Maggylamp for magnification. All samples were sorted using an identical procedure of searching for seeds within each of six channels of the sorting tray, and repeating the procedure after shaking to redistribute the sample material. All non-grass seed and seed of the grass *C. hubbardiana* were extracted, enumerated and identified by comparison with known reference specimens. All samples were analysed by a single operator. Only results for the four key food plants are reported here. Data may over-estimate the abundance of seed available to ground-foraging granivorous birds as it includes sub-surface seed not available to foragers gleaning seed from the soil surface.

Whole seeds containing an edible kernel were discriminated from damaged or immature seeds with a partially formed or absent kernel due to decay or consumption, by dissection. Whole and damaged seeds were tallied separately. Seed weights of whole seeds were measured by weighing bulk samples of usually 50 seeds using a Mettler AE260 balance after being oven dried at 70°C for 24 hours.

9.2.4.3 Statistical analysis

Seed counts were transformed to density per square metre by multiplying by 1.6 prior to analysis. Multivariate analyses of plant community composition at 35 sites in 2006 and 2007 were conducted using PRIMER version 6 software package (Clarke and Gorley 2006) as described in the previous section. Classification groups derived from these analyses were used in subsequent analyses. Variation in patterns of occurrence of seed in the late dry season (September) was modelled using the R software package (R Development Core Team 2008) with categorical factors Year, Group and Species, and binomial errors and the logit link function. The Akaike Information Criterion corrected for small sample size (AIC_c) was used to select minimum adequate models. Where data are over-dispersed the quasi-AIC_c ($QAIC_c$) was calculated using the formula of Burnham and Anderson (2002).

For individual species, data on counts of seeds were modelled by zero-inflated regression in the R software package and using poisson errors and the log link function. Zero-inflated models are capable of dealing with excess zero counts. They are two-component mixture models combining count and binary models (Zeileis *et al.* 2007). There were no goodness-of-fit tests available to assess model results. Analysis of seed counts for individual species used data from 29 sites in floristic groups 2 and 3 from classification of 2006 data.

The proportion of whole seeds was modelled by binomial modelling using Species and Period as categorical variables and data from all plots with a minimum number of 20 seeds.

9.3 RESULTS

9.3.1 Patterns in plant productivity

Patterns of variation of monthly GPP of the ephemeral component of the vegetation are strongly seasonal in accord with seasonal monsoonal rainfall (Figure 9.4). There is substantial variation in monthly GPP due to the near failure of wet season rainfall in some years including 2001/02 and 2004/05 (Figure 9.5). This inter-annual variation is demonstrated in Figure 9.6, showing the distribution of GPP in an area enclosing Helen Springs Station. The maximum GPP in each figure is scaled to a maximum value of 600 mmol CO_2 m^{-2} day^{-1}.

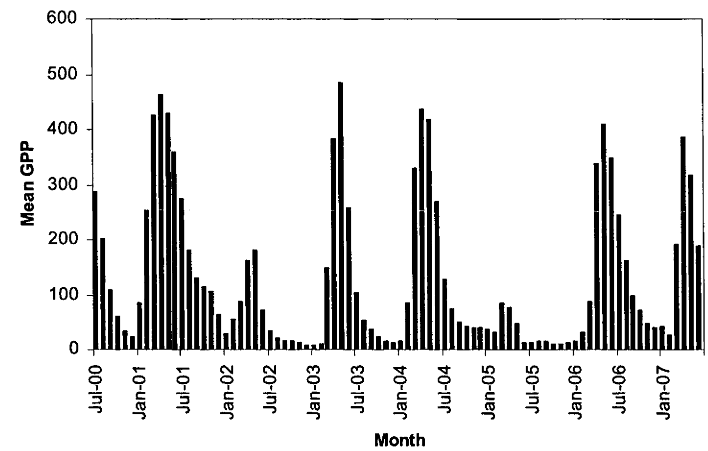


Figure 9.4 Mean GPP of raingreen component of vegetation from July 2000-June 2007 at Helen Springs Station, Barkly Tableland, NT.

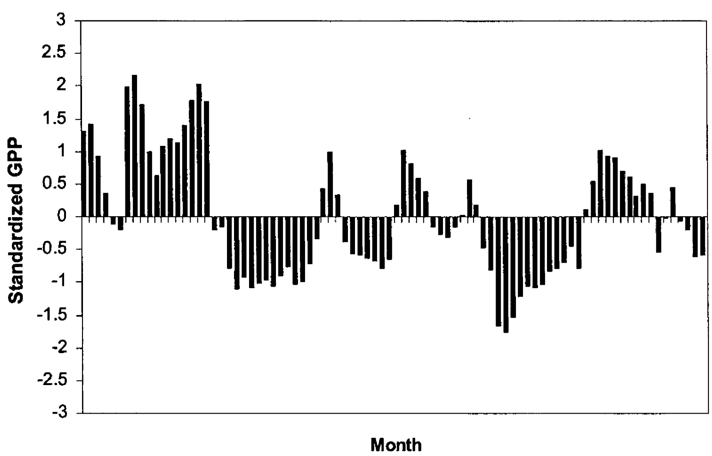
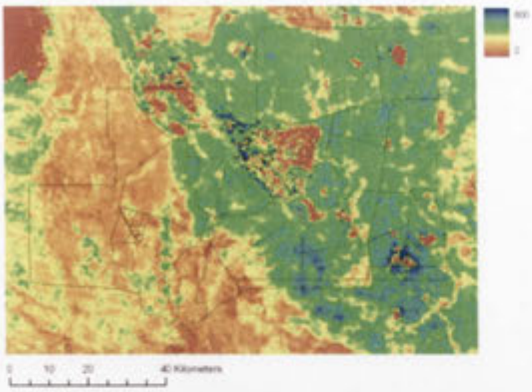
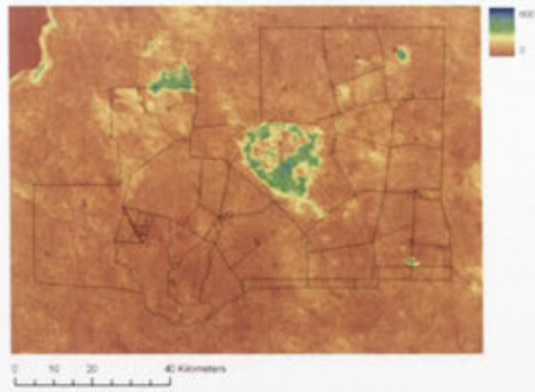


Figure 9.5 Deviation from mean monthly GPP of raingreen component of vegetation from July 2000-June 2007 at Helen Springs Station, Barkly Tableland, NT.

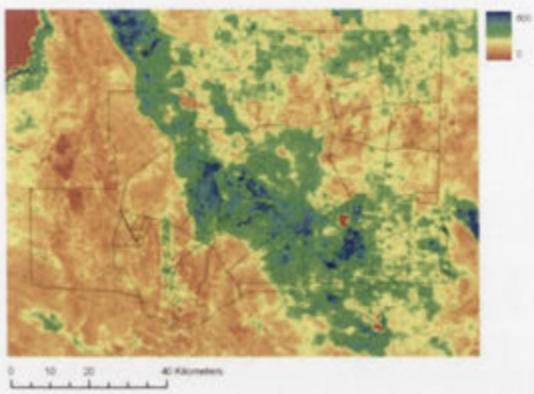
a.)


0 10 20 40 Kilometers

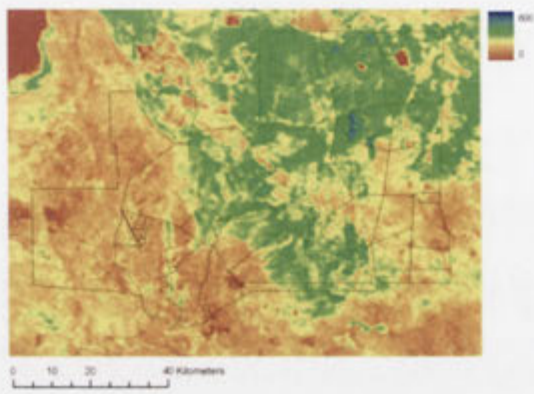
b.)


0 10 20 40 Kilometers

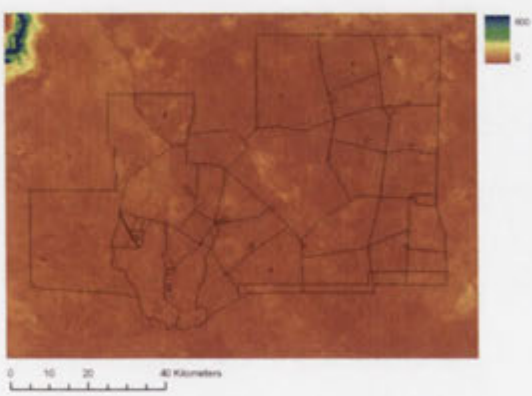
c.)


0 10 20 40 Kilometers

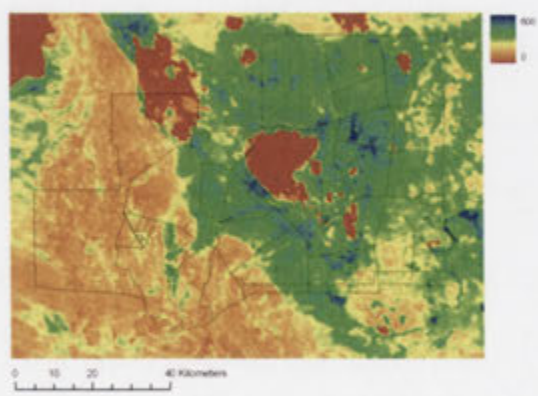
d.)


0 10 20 40 Kilometers

e.)


0 10 20 40 Kilometers

f.)


0 10 20 40 Kilometers

g.)

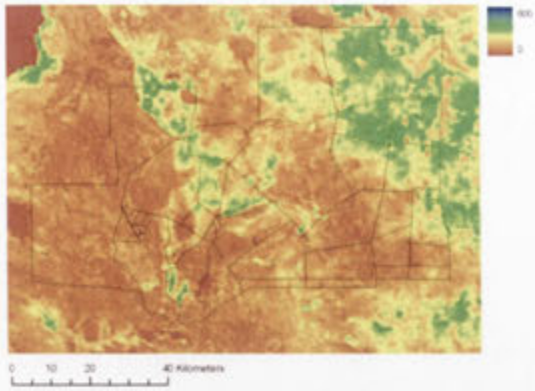


Figure 9.6 GPP (mmol CO_2 m^{-2} day^{-1}) of raingreen component of vegetation, Helen Springs Station.

a.) April 2001, b.) April 2002, c.) April 2003, d.) April 2004, e.) April 2005, f.) April 2006, g.) April 2007. Data scaled to maximum value of 600.

9.3.2 Plant community dynamics

9.3.2.1 Plant species richness

One hundred and twenty one plant taxa were identified on vegetation monitoring plots in the two sampling periods: 114 taxa in 2006 and 102 taxa in 2007. Nineteen plant taxa were only recorded in 2006; conversely, seven taxa were recorded only in 2007. Plant species richness per site differed significantly between years (paired t-test, $t = 5.28$, d.f. 34, $P<0.001$). The mean number of species per site was 26.5 in 2006 and 22.1 in 2007.

9.3.2.2 Spatial patterns in community composition

The CLUSTER procedure of 2006 floristic data revealed a classification with three groups consisting of a small heterogeneous group (group 1) of six sites mostly composed of sites situated in swamps or on drainage lines; and two larger groups (groups 2 and 3) of 18 and 11 sites situated in open Mitchell grassland (Figure 9.7). The average dissimilarity between groups 2 and 3 was 70.26. Fifty percent of the contribution to the average dissimilarity was accounted for by twelve species. Discriminating species include *Wedelia asperrima* (Diss/SD=1.42), *Trichodesma zeylanicum* (Diss/SD=1.40), and *Iseilema vaginiflorum* (Diss/SD=1.40). Group 3 had higher abundance values of the food plants *W. asperrima*, *T. zeylanicum* and *Chionachne hubbardiana*, and the perennial grass *Astrebla elymoides* (Table 9.2). MDS ordination plots show the relative abundance of food plants and dominant perennial tussock-grasses in ordination space (Figures 9.9 and 9.11) in relation to classification groups. Three species (*C. hubbardiana*, *W. asperrima* and *T. zeylanicum*) were largely confined to group 3 sites. A fourth species, *Cullen cinereum*, was abundant in group 1 sites: it was not recorded as an important food plant on the Barkly, but was known to be important elsewhere. The four perennial grass species were distributed across an edaphic gradient with *Astrebla elymoides* occupying one end of the gradient, *A. pectinata* the intermediate portion, and *A. latifolia* and *C. fallax* the upper portions of the gradient. Environment correlates of this gradient were not quantified but include a co-varying suite of characters including soil type and frequency of inundation.

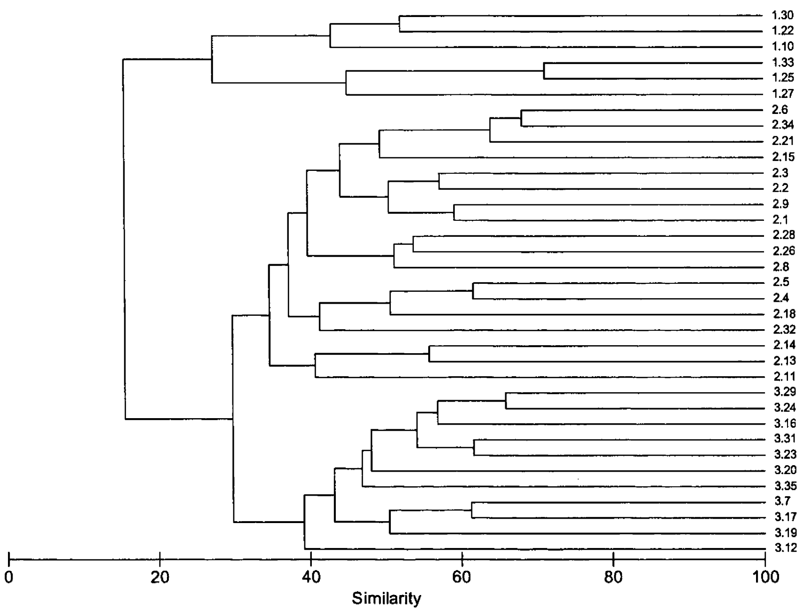


Figure 9.7 Dendrogram of classification of 2006 floristic data.

Dendrogram labelled by classification group and site.

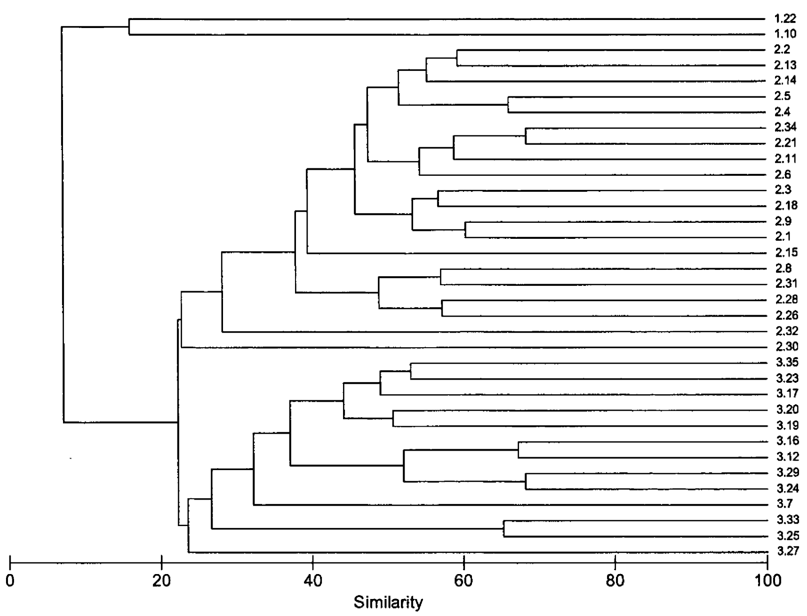


Figure 9.8 Dendrogram of classification of 2007 floristic data.

Dendrogram labelled by classification group and site.

Table 9.2 Results of SIMPER procedure, showing species contributing to 50% of cumulative average dissimilarity between groups 2 and 3 from sampling in 2006.

Average abundances for each group are based on transformed data. Diss/SD provides a measure of discriminating taxa.

Species	Group 2 Av. Abund	Group 3 Av. Abund	Av. Diss	Diss/SD	Contrib %	Cum. %
Sorghum timoriense	2.26	0.00	4.89	1.33	6.96	6.96
Iseilema vaginiflorum	1.18	2.88	4.34	1.40	6.18	13.13
Astrebla pectinata	1.97	0.78	3.44	1.31	4.90	18.03
Brachyachne convergens	0.31	1.89	3.43	1.24	4.88	22.91
Chionachne hubbardiana	0.10	1.66	3.42	1.22	4.87	27.78
Polymeria longifolia	2.07	2.30	3.30	1.26	4.69	32.47
Wedelia asperrima	0.85	1.73	2.87	1.42	4.09	36.56
Astrebla elymoides	0.52	1.35	2.53	1.13	3.61	40.17
Eragrostis tenellula	1.10	0.21	2.10	0.77	2.98	43.15
Trichodesma zeylanicum	0.47	1.22	2.00	1.40	2.85	46.00
Flaveria australasica	0.80	0.50	1.80	0.97	2.56	48.56
Glycine falcata	0.83	0.11	1.61	1.05	2.29	50.85

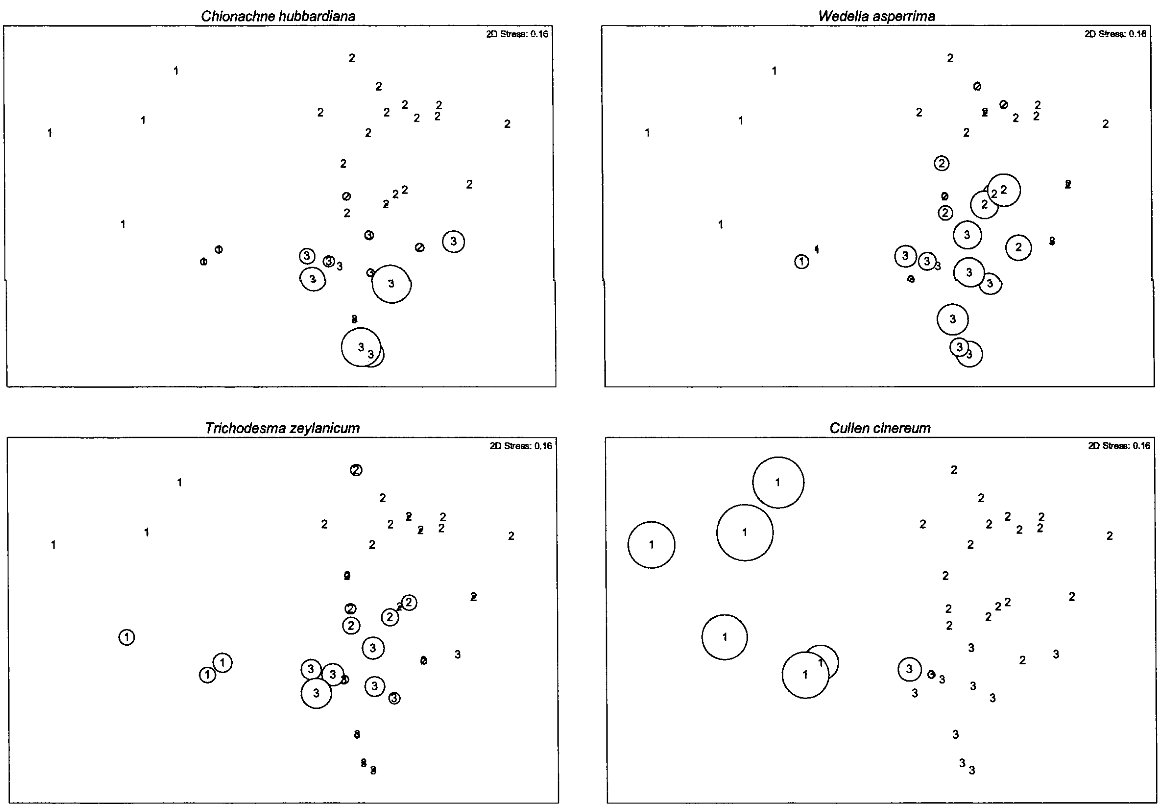


Figure 9.9 Plots of MDS ordination of 2006 floristic data.

Plots overlain by classification group number and abundance of the food plants *C. hubbardiana*, *W. asperrima*, *T. zeylanicum* and *C. cinereum*.

The CLUSTER procedure of 2007 floristic data similarly revealed a classification consisting of three groups: an outlier group (group 1) of 2 sites; and two larger groups (groups 2 and 3) of 20 and 13 sites (Figure 9.8). The composition of group 3 was relatively constant between years: ten sites were present in both years. The average dissimilarity between groups 2 and 3 was 77.74. Fifty percent of the contribution to the average dissimilarity was accounted for by twelve species. Discriminating species include *Astrebla pectinata* (Diss/SD=1.48), *Polymeria longifolia* (Diss/SD=1.33), and *Rhynchosia minima* (Diss/SD=1.31). Food plants of the Flock Bronzewing Pigeon are not included in the taxa contributing to average dissimilarity between groups (Table 9.3). MDS ordination plots show the relative abundance of food plants and perennial tussock-grasses in ordination space in relation to classification groups. All food plant species are less abundant, and segregation of classification groups in MDS space is less evident (Figures 9.10 and 9.12).

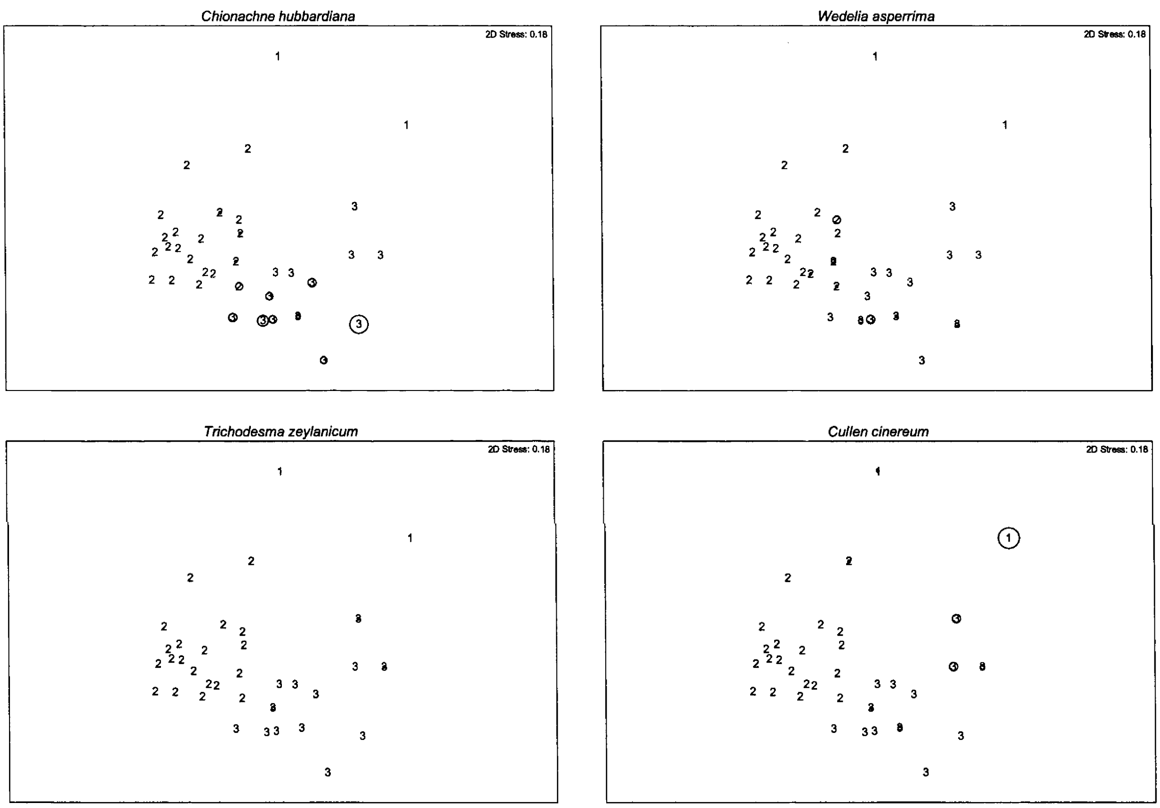


Figure 9.10 Plots of MDS ordination of 2007 floristic data.

Plots overlain by classification group number and abundance of the food plants *C. hubbardiana*, *W. asperrima*, *T. zeylanicum* and *C. cinereum*.

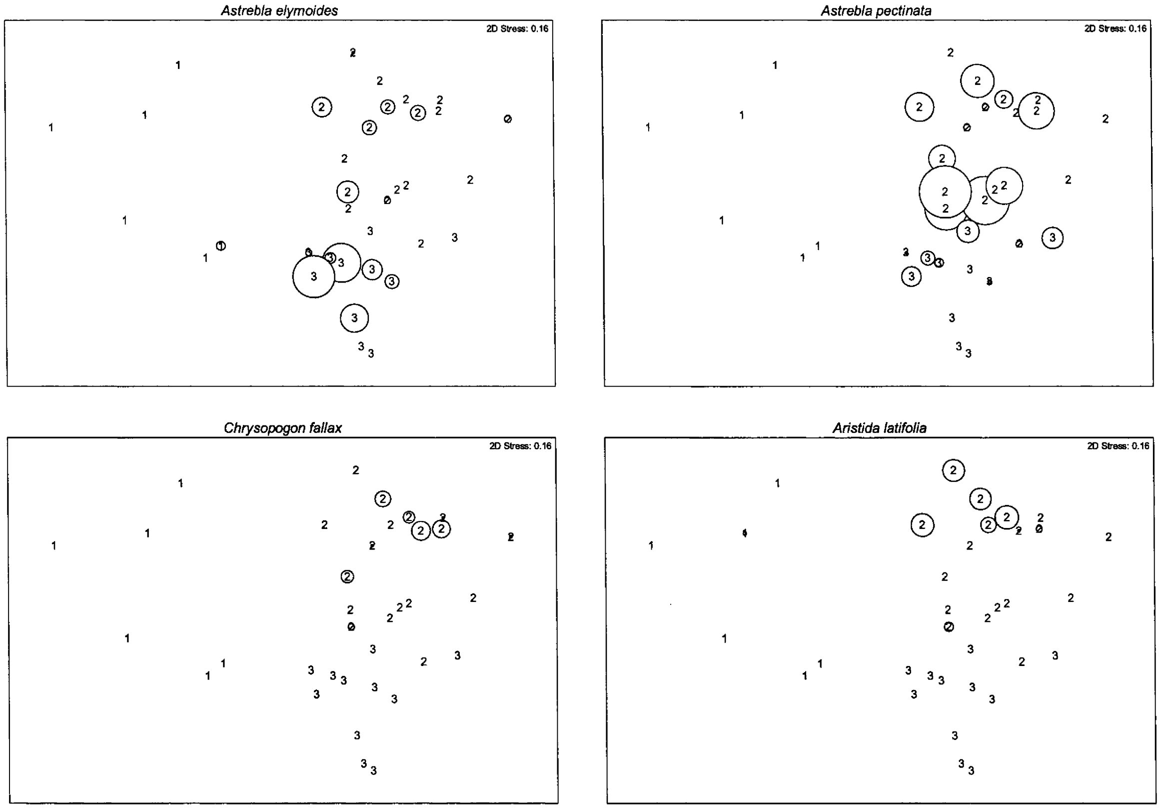


Figure 9.11 Plots of MDS ordination of 2006 floristic data overlain by classification group number and abundance of dominant perennial tussock-grass species.

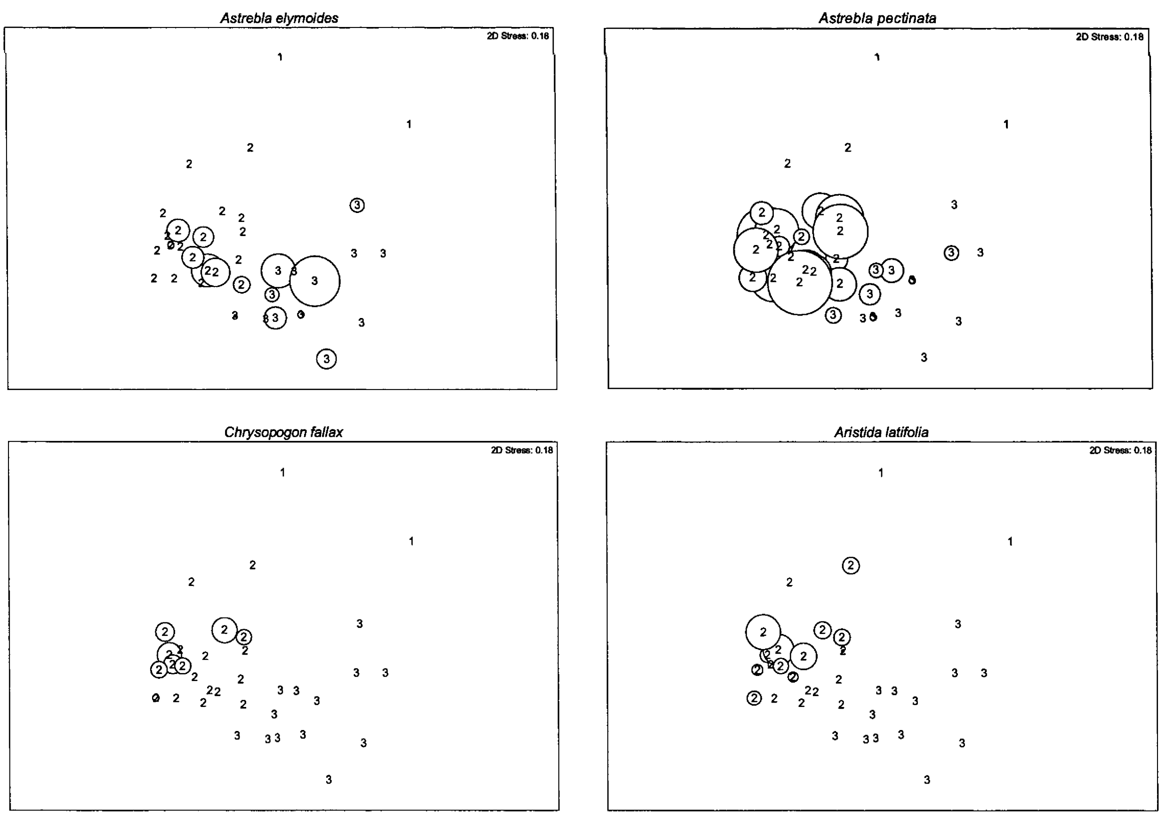


Figure 9.12 Plots of MDS ordination of 2007 floristic data overlain by classification group number and abundance of dominant perennial tussock-grass species.

Bubble-plots of the combined dry weight of seed of four principal food plants show that the biomass of preferred seeds is greater in classification group 3 sites, and that the biomass of seed differed between years (Figure 9.13).

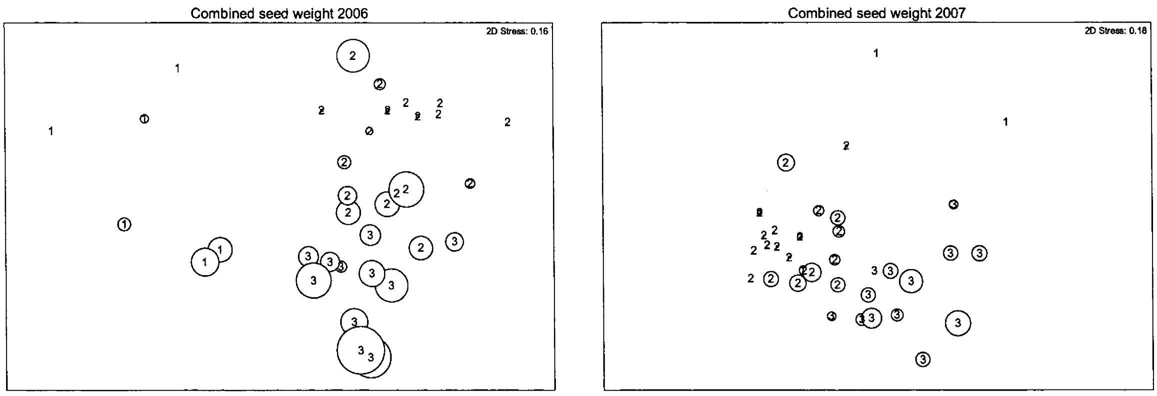


Figure 9.13 Plots of MDS ordination of 2006 and 2007 floristic data overlain by classification group number and combined dry weight of seed of main food plants of Flock Bronzewing Pigeon.

Table 9.3 Results of SIMPER procedure, showing species contributing to 50% of cumulative average dissimilarity, between groups 2 and 3 from sampling in 2007.

Average abundances for each group are based on transformed data. Diss/SD provides a measure of discriminating taxa.

Species	Group 2 Av. Abund	Group 3 Av. Abund	Av. Diss	Diss/SD	Contrib %	Cum. %
Astrebla pectinata	2.90	0.71	5.98	1.48	7.69	7.69
Sorghum timoriense	2.19	0.05	5.53	1.11	7.12	14.80
Iseilema vaginiflorum	0.88	2.16	4.42	1.05	5.68	20.49
Polymeria longifolia	1.91	1.50	4.36	1.33	5.61	26.10
Astrebla elymoides	0.69	1.18	3.15	1.03	4.05	30.15
Rhynchosia minima	0.97	1.30	3.03	1.31	3.90	34.05
Aristida latifolia	1.00	0.00	2.48	1.02	3.19	37.24
Goodenia strangfordii	0.19	1.08	2.45	1.10	3.16	40.39
Neptunia gracilis	0.97	0.20	2.34	1.14	3.01	43.30
Brachyachne convergens	0.10	1.01	2.33	1.06	3.00	46.40
Glycine falcata	0.83	0.07	2.04	1.04	2.62	49.02
Streptoglossa bubakii	0.82	0.17	2.01	0.85	2.58	51.60

9.3.2.3 Multivariate analysis of inter-annual patterns

The ANOSIM procedure revealed a significant difference in compositional structure of plant community between years for both transformed cover data (sample statistic = 0.129, $P<0.001$), and presence/absence data (sample statistic = 0.13, $P<0.001$). The average dissimilarity between years was 74.43 for transformed cover data, and 63.06 for presence/absence data. For cover data analysis, fifty percent of the contribution to the average dissimilarity was accounted for by 16 species. Discriminating species include *Polymeria longifolia* (Diss/SD=1.28), and *Astrebla pectinata* (Diss/SD=1.22). Discriminant values are low and maximum % contribution of individual species is low (*A. pectinata*, 5.5%) (Table 9.4). For presence/absence data fifty percent of the contribution to the average dissimilarity was accounted for by 31 species. Discriminating species include *T. zeylanicum* (Diss/SD=1.34), *Eragrostis tenellula* (Diss/SD=1.25), and *W. asperrima* (Diss/SD=1.16). Discriminant values are low and maximum % contribution of individual species is low (*T. zeylanicum*, 2.2%) (Table 9.5).

Table 9.4 Results of SIMPER procedure of average cover data, showing species contributing to 50% of cumulative average dissimilarity.

Average abundances for each group are based on transformed data. Diss/SD provides a measure of discriminating taxa.

Species	2006 Av. Abund	2007 Av. Abund	Av. Diss	Diss/SD	Contrib %	Cum.%
Astrebla pectinata	1.26	1.92	4.12	1.22	5.54	5.54
Sorghum timoriense	1.16	1.27	3.89	0.95	5.23	10.77
Polymeria longifolia	1.94	1.65	3.80	1.28	5.10	15.87
Iseilema vaginiflorum	1.51	1.31	3.49	1.05	4.69	20.56
Astrebla elymoides	0.71	0.84	2.39	0.96	3.21	23.78
Wedelia asperrima	1.03	0.10	2.25	0.97	3.02	26.80
Rhynchosia minima	0.46	1.03	2.14	1.12	2.88	29.68
Brachyachne convergens	0.78	0.43	2.02	0.84	2.71	32.39
Cullen cinereum	0.82	0.14	2.01	0.56	2.70	35.09
Eragrostis tenellula	0.82	0.10	1.79	0.72	2.41	37.50
Streptoglossa bubakii	0.48	0.53	1.65	0.86	2.22	39.71
Trichodesma zeylanicum	0.76	0.02	1.60	1.00	2.15	41.86
Aristida latifolia	0.34	0.57	1.59	0.81	2.14	44.00
Chionachne hubbardiana	0.60	0.23	1.57	0.69	2.11	46.10
Neptunia gracilis	0.24	0.65	1.53	0.97	2.06	48.16
Glycine falcata	0.48	0.50	1.51	0.93	2.02	50.18

Table 9.5 Results of SIMPER procedure of presence/absence data, showing species contributing to 50% of cumulative average dissimilarity.

Average abundances for each group are based on transformed data. Diss/SD provides a measure of discriminating taxa.

Species	2006 Av. Abund	2007 Av. Abund	Av. Diss	Diss/SD	Contrib %	Cum.%
Trichodesma zeylanicum	0.69	0.09	1.36	1.34	2.16	2.16
Eragrostis tenellula	0.66	0.11	1.31	1.25	2.07	4.23
Wedelia asperrima	0.66	0.23	1.22	1.16	1.94	6.17
Spermacoce pogostoma	0.77	0.40	1.19	1.09	1.89	8.06
Ptilotus spicatus	0.60	0.26	1.15	1.08	1.82	9.88
Neptunia gracilis	0.34	0.57	1.11	1.02	1.76	11.64
Corchorus tridens	0.57	0.31	1.10	1.03	1.75	13.39
Operculina aequisepala	0.60	0.49	1.07	0.98	1.70	15.09
Glycine falcata	0.57	0.49	1.06	0.98	1.69	16.78
Sorghum timoriense	0.46	0.51	1.06	0.98	1.69	18.47
Brachyachne convergens	0.51	0.46	1.06	0.98	1.69	20.16
Goodenia strangfordii	0.51	0.51	1.06	0.98	1.68	21.84
Neptunia monosperma	0.46	0.49	1.05	0.98	1.67	23.51
Astrebla elymoides	0.46	0.46	1.05	0.97	1.67	25.18
Desmodium muelleri	0.57	0.57	1.05	0.96	1.66	26.84
Abelmoschus ficulneus	0.57	0.57	1.05	0.96	1.66	28.50
Hibiscus trionum	0.49	0.43	1.05	0.98	1.66	30.16
Indigofera ewartiana	0.40	0.46	1.04	0.96	1.65	31.81
Sida spinosa	0.54	0.74	1.04	0.94	1.65	33.45
Alysicarpus muelleri	0.37	0.46	1.03	0.96	1.63	35.09
Streptoglossa bubakii	0.46	0.34	1.01	0.95	1.61	36.70
Chionachne hubbardiana	0.43	0.34	1.00	0.93	1.59	38.29
Astrebla pectinata	0.60	0.71	0.99	0.90	1.57	39.86
Rhynchosia minima	0.60	0.69	0.99	0.91	1.57	41.43
Blumea tenella	0.46	0.03	0.96	0.91	1.52	42.95
Flaveria australasica	0.46	0.09	0.93	0.92	1.48	44.43
Aristida latifolia	0.26	0.37	0.92	0.86	1.46	45.89
Digitaria ctenantha	0.26	0.34	0.88	0.84	1.40	47.29
Cucumis melo	0.37	0.11	0.86	0.80	1.36	48.65
Crotalaria medicaginea	0.17	0.37	0.85	0.83	1.34	50.00
Leptopus decaisnei	0.40	0.03	0.83	0.81	1.31	51.31

9.3.2.4 Species frequency of occurrence on plot scale

Binomial modelling of presence/absence data revealed inter-annual differences in the frequency of occurrence at the plot scale for 13 plant species, most of which were annual forbs (Table 9.6) which declined in occurrence between years. The explained deviance of most models was less than 30% and therefore relatively weak. The food plant *Trichodesma zeylanicum* declined from a probability of occurrence of 0.69 in 2006 to 0.09 in 2007; similarly *Wedelia asperrima* declined from a probability of occurrence of 0.66 in 2006 to 0.23 in 2007. The remaining species are not considered major plants of Flock Bronzewing Pigeons, though seed of both *Leptopus decaisnei* and *Phyllanthus maderaspatensis* are of minor importance (Chapter 7).

Table 9.6 Results of binomial modelling of inter-annual differences in probability of occurrence at plot scale.

Species	Life history, growth form	2006 Probability (95% c. l.)	2007 Probability (95% c. l.)	Sig.	pcdev
Trichodesma zeylanicum	Annual, forb	0.69 (0.52-0.82)	0.09 (0.01-0.41)	<0.001	31.4
Eragrostis tenellula	Annual, grass	0.66 (0.49-0.80)	0.11 (0.02-0.46)	<0.001	25.1
Blumea tenella	Annual, forb	0.46 (0.30-0.62)	0.03 (0.00-0.24)	<0.01	26.1
Wedelia asperrima	Annual, forb	0.66 (0.49-0.80)	0.23 (0.05-0.63)	<0.001	14.0
Spermacoce pogostoma	Annual, forb	0.77 (0.62-0.89)	0.40 (0.10-0.81)	<0.01	10.8
Flaveria australasica	Annual, forb	0.46 (0.30-0.62)	0.09 (0.01-0.39)	<0.01	16.0
Leptopus decaisnei	Annual, forb	0.40 (0.25-0.57)	0.03 (0.00-0.24)	<0.01	22.7
Ptilotus spicatus	Perennial root, forb	0.60 (0.43-0.75)	0.26 (0.06-0.65)	<0.01	9.0
Phyllanthus maderaspatensis	Annual, forb	0.97 (0.88-1.00)	0.66 (0.02-0.99)	<0.01	19.5
Cucumis melo	Annual, herbaceous vine	0.37 (0.22-0.54)	0.11 (0.02-0.45)	<0.05	8.4
Cleome viscosa	Annual, forb	0.31 (0.18-0.48)	0.11 (0.02-0.46)	<0.05	5.9
Sida laevis	Annual/perennial, forb	0.09 (0.02-0.21)	0.31 (0.03-0.86)	<0.05	8.6
Euphorbia alsiniflora	Annual, forb	0.03 (0.00-0.12)	0.31 (0.00-0.98)	<0.05	17.9

9.3.2.5 Inter-annual variation in summary variables

There were significant differences between years for several classes of habitat cover. Perennial grass basal area cover, perennial grass cover, litter cover and soil cover increased; herb cover and total plant cover decreased; there was no significant difference in annual measures of annual grass cover (Table 9.7).

Table 9.7 Results of two-tailed tests of significance of parametric and non-parametric paired sample tests.

	Mean %cover estimates		Paired sample t-test			Wilcoxon paired sample test
Variable	**Year 1**	**Year 2**	***t***	**df**	***P***	***P***
Annual grass cover	17.9	13.3				ns
Herb cover	23.7	16.1				<0.01
Litter cover	0.5	4.0				<0.001
Perennial grass basal cover	3.6	6.1	-4.15	34	<0.001	
Perennial grass cover	7.5	12.9				<0.001
Soil cover	36.2	48.8	-3.45	34	<0.01	
Total plant cover	56.9	44.8	3.06	34	<0.01	
Cattle index (0-10)	0.6	1.4				<0.05

9.3.3 Seed dynamics

The combined dry weight (expressed as g/m^2) of seeds of four key food plants varied between sites and years (Figure 9.14). Seed dry weight ranged from 0-9.7 g/m^2 in September 2006 and from 0-2.7 g/m^2 in September 2007. The total dry weight of seed summed over sites was estimated at 68.1 g/m^2 in September 2006 and 20.5 g/m^2 in September 2007.

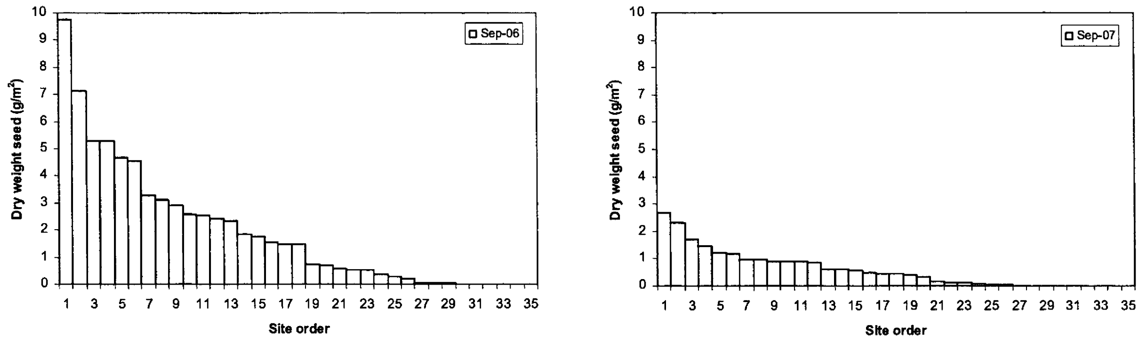


Figure 9.14 Combined dry weight (expressed as g/m^2) of seed of four food plants on 35 sample plots in Mitchell grass grasslands in September 2006 and 2007, in decreasing rank order by weight.

Binomial modelling of the occurrence of whole seed or four species in three floristic groups in two years indicated that there was no strong effect of year (Table 9.8), and that most of the deviance in the model could be attributed to differences in the patterns of occurrence of the species *Chionachne hubbardiana* between floristic groups (Tables 9.9 and 9.10). *Chionachne hubbardiana* occurred in group 3 sites with an estimated probability of 0.53, and at group 2 and 1 sites with a probability of 0.18 and 0.15.

Table 9.8 Model selection criteria for binomial models of occurrence of whole seed of four food plants in three floristic groups over two years.

Model type	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
GROUP+SPECIES	-165.84	7	291.56	0.00	0.49	14.5
GROUP+SPECIES+YEAR	-164.58	8	291.60	0.03	0.48	15.2
GROUP*SPECIES	-162.29	13	298.72	7.16	0.01	16.4
GROUP*SPECIES+YEAR	-160.99	14	298.80	7.24	0.01	17.0
GROUP	-178.14	4	305.64	14.08	0.00	8.2
GROUP+YEAR	-176.98	5	305.81	14.25	0.00	8.8
SPECIES	-183.25	5	316.21	24.65	0.00	5.6
SPECIES+YEAR	-182.14	6	316.47	24.91	0.00	6.1
YEAR*SPECIES	-181.36	9	321.58	30.02	0.00	6.5
Null model	-194.05	2	327.90	36.34	0.00	0.0
YEAR	-193.02	3	328.25	36.69	0.00	0.5

Table 9.9 Parameter estimates of preferred model.

Model parameters	Estimate	Std. error	z value	Pr(>|z|)	Sig.
Constant	0.121	0.332	0.365	0.71	ns
GROUP2	-1.622	0.321	-5.058	0.00	***
GROUP1	-1.878	0.414	-4.541	0.00	***
SPECIESPhyllanthus	1.662	0.395	4.212	0.00	***
SPECIESTrichodesma	1.594	0.393	4.054	0.00	***
SPECIESWedelia	1.065	0.387	2.750	0.01	**

Table 9.10 Estimates of probability of occurrence of whole seed of four food plants in three floristic groups in Mitchell grass grasslands.

Floristic groups defined from classification of 2006 data.

Species	Group 1	Group 2	Group 3
Chionachne	0.15 (0.04-0.42)	0.18 (0.06-0.44)	0.53 (0.37-0.69)
Phyllanthus	0.48 (0.09-0.90)	0.54 (0.13-0.90)	0.86 (0.59-0.96)
Trichodesma	0.46 (0.08-0.89)	0.52 (0.12-0.90)	0.85 (0.58-0.96)
Wedelia	0.33 (0.05-0.82)	0.39 (0.08-0.83)	0.77 (0.45-0.93)

Analysis of seed abundance data using zero-inflated regression models yielded similar models for all four species (Tables 9.11 - 9.14). In each model the estimated density of seed declined from the mid-to late dry season of 2006 to reduced levels in 2007 (Figure 9.15). Seed densities decline over the wet season due to processes including consumption, burial and germination. For *C. hubbardiana* estimated density in group 3 sites declined to a minimum after the wet season with a slight increase in June 2007 perhaps due to limited seed production. Estimated density in group 2 sites was low in all months, a result consistent with analysis of patterns of occurrence. For *Phyllanthus lacerosus* the trends between floristic groups were similar except that density declined markedly in group 3 sites between samples in the mid and late dry season. This may be due to removal by vertebrate and invertebrate consumers. There is some evidence of recruitment of new seed in the early dry season of 2007. For *Trichodesma zeylanicum* the temporal patterns of estimated density were similar between floristic groups. For group 2 and to some extent for group 3 sites there was an increase in seed density from the early dry season. Nutlets of *T. zeylanicum* dehisce from the plant relatively late in the dry season and are not immediately available to foraging birds. Similar temporal patterns, and delayed seed fall was also observed in *W. asperrima*.

Table 9.11 Model selection criteria for zero-inflated poisson models for counts of whole *Chionachne hubbardiana* seed on 29 plots in Mitchell grasslands.

Model type	Log likelihood	k	AICc	d.AICc
PERIOD*GROUP | PERIOD*GROUP	-1782.49	24	3571.12	0.00
PERIOD*GROUP | PERIOD+GROUP	-1783.34	19	3572.82	1.70
PERIOD*GROUP | GROUP	-1784.21	14	3574.57	3.45
PERIOD*GROUP | PERIOD	-1813.26	18	3632.67	61.55
PERIOD*GROUP | 1	-1813.84	13	3633.83	62.71
PERIOD+GROUP | PERIOD+GROUP	-1856.16	14	3718.45	147.34
PERIOD+GROUP | GROUP	-1857.03	9	3720.20	149.08
PERIOD+GROUP | PERIOD	-1886.08	13	3778.30	207.18
PERIOD+GROUP | 1	-1886.66	8	3779.46	208.34
PERIOD | PERIOD*GROUP	-2097.39	18	4200.93	629.81
PERIOD | GROUP	-2099.12	8	4204.38	633.26
PERIOD | PERIOD	-2128.17	12	4262.48	691.36
PERIOD | 1	-2128.75	7	4263.64	692.52
GROUP | PERIOD*GROUP	-2272.51	14	4551.16	980.04
GROUP | GROUP	-2274.24	4	4554.61	983.49
GROUP | PERIOD	-2303.29	8	4612.71	1041.60
GROUP | 1	-2303.87	3	4613.87	1042.76
Null model	-2598.86	2	5203.85	1632.73

Table 9.12 Model selection criteria for zero-inflated poisson models for counts of whole *Phyllanthus lacerosus* seed on 29 plots in Mitchell grassland.

Model type	Log likelihood	k	AICc	d.AICc
PERIOD*GROUP | PERIOD*GROUP	-1215.04	24	2436.22	0.00
PERIOD*GROUP | PERIOD+GROUP	-1216.33	19	2438.79	2.58
PERIOD*GROUP | GROUP	-1217.63	14	2441.41	5.19
PERIOD*GROUP | PERIOD	-1223.03	18	2452.20	15.98
PERIOD*GROUP | 1	-1224.24	13	2454.61	18.40
PERIOD+GROUP | PERIOD+GROUP	-1319.08	14	2644.30	208.08
PERIOD+GROUP | GROUP	-1320.38	9	2646.91	210.69
PERIOD+GROUP | PERIOD	-1325.78	13	2657.70	221.48
PERIOD+GROUP | 1	-1326.99	8	2660.11	223.90
PERIOD | PERIOD*GROUP	-1335.50	18	2677.15	240.93
PERIOD | GROUP	-1338.10	8	2682.34	246.12
PERIOD | PERIOD	-1343.49	12	2693.13	256.91
PERIOD | 1	-1344.70	7	2695.54	259.33
GROUP | PERIOD*GROUP	-1514.78	14	3035.71	599.49
GROUP | GROUP	-1517.38	4	3040.89	604.68
GROUP | PERIOD	-1522.77	8	3051.68	615.47
GROUP | 1	-1523.98	3	3054.10	617.88
Null model	-1545.73	2	3097.61	661.39

Table 9.13 Model selection criteria for zero-inflated poisson models for counts of whole *Trichodesma zeylanicum* seed on 29 plots in Mitchell grassland.

Model type	Log likelihood	k	AICc	d.AICc
PERIOD*GROUP | PERIOD*GROUP	-3861.68	24	7729.50	0.00
PERIOD*GROUP | PERIOD+GROUP	-3866.07	19	7738.28	8.78
PERIOD*GROUP | GROUP	-3866.67	14	7739.47	9.98
PERIOD*GROUP | PERIOD	-3878.51	18	7763.17	33.67
PERIOD*GROUP | 1	-3879.03	13	7764.20	34.71
PERIOD+GROUP | PERIOD+GROUP	-4064.65	14	8135.44	405.94
PERIOD+GROUP | GROUP	-4065.25	9	8136.63	407.14
PERIOD+GROUP | PERIOD	-4077.09	13	8160.33	430.83
PERIOD+GROUP | 1	-4077.61	8	8161.36	431.87
PERIOD | PERIOD*GROUP	-4124.16	18	8254.46	524.96
PERIOD | GROUP	-4129.15	8	8264.43	534.94
PERIOD | PERIOD	-4140.99	12	8288.13	558.63
PERIOD | 1	-4141.51	7	8289.16	559.67
Null model	-4856.86	2	9719.86	1990.37
GROUP | 1	-4779.92	3	9565.99	1836.49
GROUP | PERIOD	-4779.41	8	9564.95	1835.46
GROUP | GROUP	-4767.56	4	9541.26	1811.76
GROUP | PERIOD*GROUP	-4762.57	14	9531.28	1801.78

Table 9.14 Model selection criteria for zero-inflated poisson models for counts of whole *Wedelia asperrima* seed on 29 plots in Mitchell grassland.

Model type	Log likelihood	k	AICc	d.AICc
PERIOD*GROUP | PERIOD*GROUP	-15380.25	24	30766.64	0.00
PERIOD*GROUP | PERIOD+GROUP	-15381.89	19	30769.93	3.29
PERIOD*GROUP | GROUP	-15382.97	14	30772.09	5.45
PERIOD*GROUP | PERIOD	-15388.64	18	30783.42	16.78
PERIOD*GROUP | 1	-15389.64	13	30785.43	18.79
PERIOD+GROUP | PERIOD+GROUP	-15822.38	14	31650.90	884.26
PERIOD+GROUP | GROUP	-15823.46	9	31653.06	886.42
PERIOD+GROUP | PERIOD	-15829.13	13	31664.39	897.76
PERIOD+GROUP | 1	-15830.13	8	31666.40	899.76
Null model	-20307.70	2	40621.54	9854.90
GROUP | 1	-19626.80	3	39259.73	8493.09
PERIOD | 1	-16767.65	7	33541.43	2774.80
PERIOD | GROUP	-16760.98	8	33528.10	2761.46
GROUP | PERIOD	-19625.79	8	39257.73	8491.09
GROUP | GROUP	-19620.13	4	39246.40	8479.76
PERIOD | PERIOD	-16766.64	12	33539.43	2772.79
PERIOD | PERIOD*GROUP	-16758.25	18	33522.65	2756.01
GROUP | PERIOD*GROUP	-19617.40	14	39240.94	8474.31

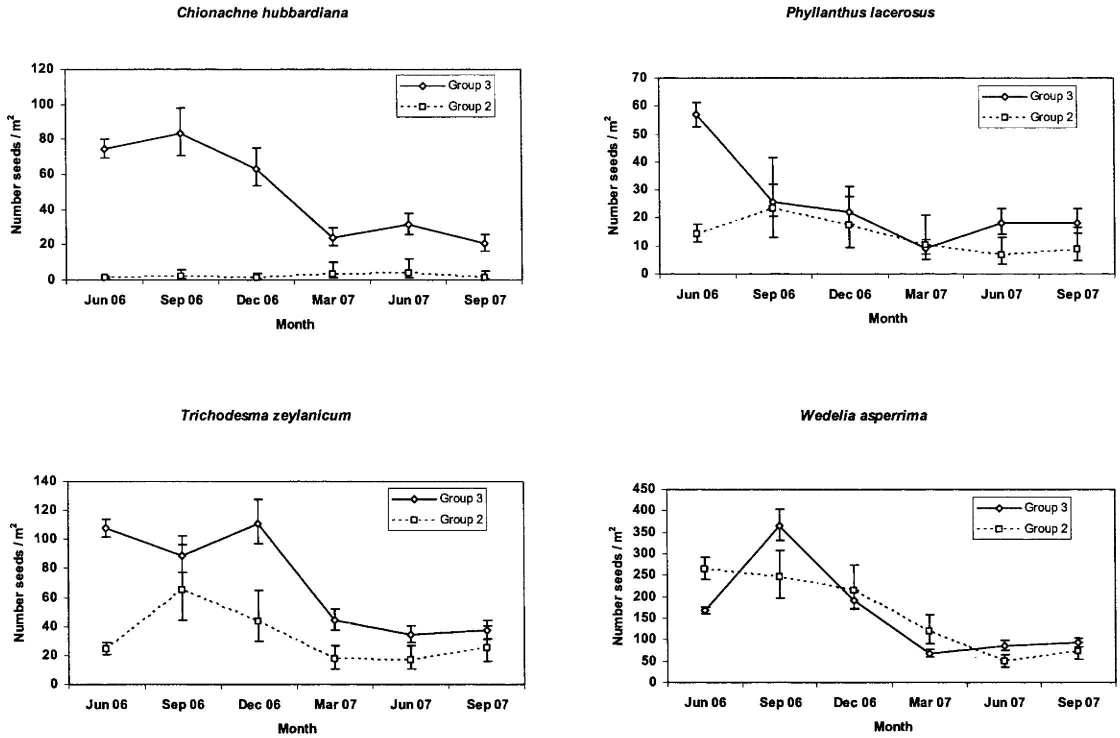


Figure 9.15 Estimated density (± 95% confidence limits) of whole seed in two habitats in Mitchell grassland.

Floristic groups were derived from classification of 2006 plant abundance data. Group 3 sites had higher abundance values of the food plants *W. asperrima*, T. *zeylanicum*, *Chionachne hubbardiana*, and the perennial grass *Astrebla elymoides.*

Maximum seed densities per plot were measured in September 2006 for each species: *W. asperrima* 1,670 seeds/m^2; *T. zeylanicum* 454 seeds/m^2; *C. hubbardiana* 371 seeds/m^2; *P. lacerosus* 256 seeds/m^2. The proportion of whole seed varied between species and periods (Table 9.15, Figure 9.16), with *T. zeylanicum* and *W. asperrima* exhibiting similar temporal patterns. In all species the spatial variability in proportion of whole seeds increased through time.

Table 9.15 Results of binomial modelling of proportion of whole seeds in soil seed samples.

Model type	Log likelihood	k	AICc	d.AICc	wi	pcdev
SPECIES*PERIOD	-2161.83	25	4378.57	0.00	1.00	58.56
SPECIES+PERIOD	-2312.45	10	4645.69	267.12	0.00	54.57
SPECIES	-2684.98	5	5380.17	1001.59	0.00	44.72
Null model	-4375.04	2	8754.12	4375.55	0.00	0.00
PERIOD	-4003.93	7	8022.26	3643.68	0.00	9.82

Table 9.16 Proportion of whole seed in four key food plants and four annual grass species in savanna woodland.

Source: Dostine *et al.* (2001), ag annual grass.

	Proportion of whole seed		
Species	**Sep 06**	**Sep 07**	**July 98***
Chionachne hubbardiana (ag)	0.66	0.43	
Phyllanthus lacerosus (forb)	0.56	0.48	
Trichodesma zeylanicum (forb)	0.92	0.76	
Wedelia asperrima (forb)	0.90	0.73	
Eriachne ciliata (ag)			0.41
Mnesithea formosa (ag)			0.59
Schizachyrium sp. (ag)			0.70
Sorghum sp. (ag)			0.41

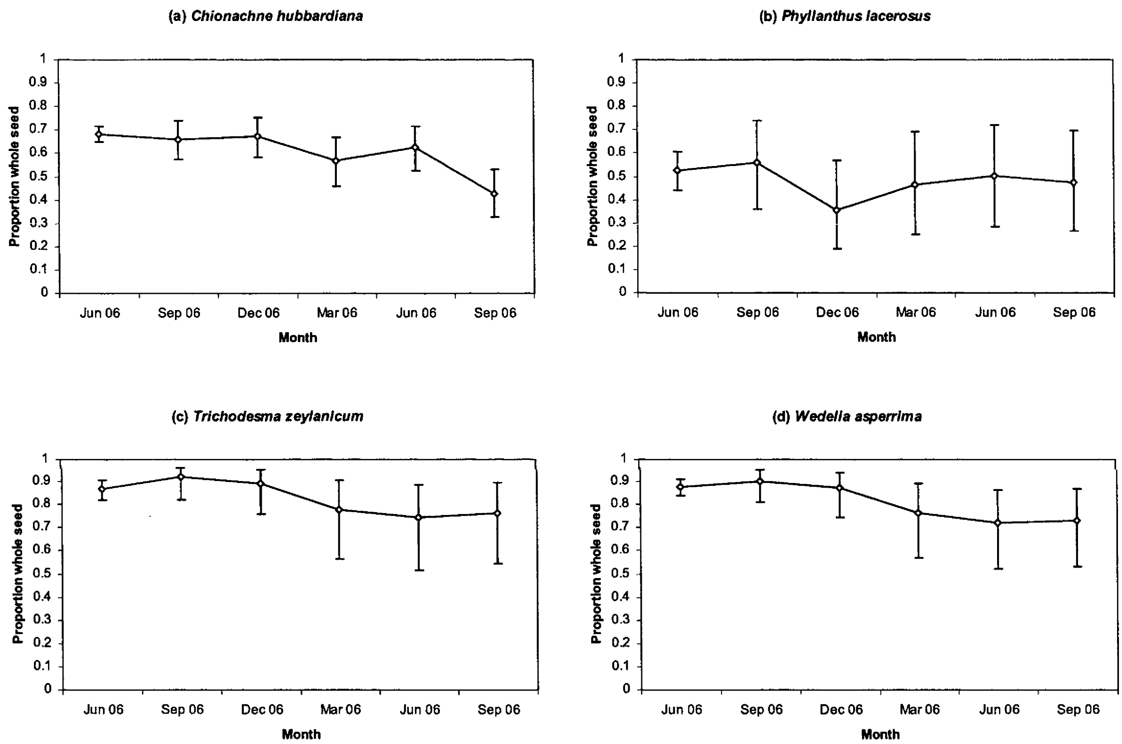


Figure 9.16 Modelled proportion of whole seeds of four species (± 95% confidence limits) in plots in Mitchell grassland.

9.4 DISCUSSION

This study documents spatial and temporal variation in resources available to Flock Bronzewing Pigeons. Plants known to be key producers of seed for this species tend to co-occur in similar environments and consistently occupy part of the sampled ordination space. Sampling was confined to a restricted portion of the soil/landform gradient in Mitchell grasslands: this was sufficient to identify differential responses by the dominant perennial tussock-grass species and to suggest that pigeon resources are associated with that part of the gradient occupied by *Astrebla elymoides*. This species frequently occupies wetter or more frequently inundated parts of Mitchell grasslands (Milson 2000), though is not confined to such habitats and the three common species of *Astrebla* frequently co-occur. Additional sampling across a larger soil/landform gradient would have identified the environmental attributes associated with individual perennial grass species, but was considered to be beyond the scope of this study.

9.4.1 Inter-annual differences in plant community composition

Multivariate and univariate statistical methods identified differences in plant community composition between years. Orr (1981) emphasised the importance of the context of rainfall history and recent rainfall events on botanical composition of Mitchell grasslands. The sequence of rainfall events determines the competitive interactions between perennial tussocks and annual grasses and forbs. The year preceding the commencement of sampling (2004/05) was a year of below average rainfall with a seasonal rainfall percentage rank of 4.5%; the wet season of 2005/06 was above average with a seasonal rainfall percentage rank of 93.5%, and well-above average April rainfall. This combination of events is extremely infrequent. Rainfall was recorded in April in 32 years of the 63 year rainfall record; of these only three monthly totals exceeded 100 mm i.e. P=0.048, or frequency of less than 1 in 20 years. This raises a number of considerations. Firstly, it supports the assertion of Phelps *et al.* (1993) and others that rangeland monitoring needs to be long-term to capture consequences of infrequent major climatic events. Secondly, it raises the possibility that a particular sequence of rainfall history is required to initiate pulses of seeding of preferred food plants and that these circumstances arise at a given locality with extreme rarity and that extensive searching is required to locate and exploit rare habitat opportunities.

9.4.2 Patterns of seed abundance

In concert with variation in the abundance of food plants, there was marked spatial and temporal variation in the availability of seed resources for Flock Bronzewing Pigeons. Binomial modelling suggested that the patterns of occurrence of whole seed in different floristic groups were similar between three of the preferred four species, with the exception of *C. hubbardiana*. Zero-inflated regression modelling revealed temporal patterns in seed abundance: in all four species the density of seed in the dry season differed between years, and was markedly lower in 2007. Densities of all four species declined to low but not near-zero levels in late wet season samples. This contrasts with the precipitous depletion by germination of annual grass seeds available to granivorous bird in northern savanna woodlands (Woinarski and Tidemann 1991, Dostine *et al.* 2001). Gutierrez *et al.* (2000) measured significantly higher soil seed densities in semi-arid herb and shrub communities in response to high rainfall during an ENSO year. Soil seed densities generally exceeded those measured in this study.

9.4.3 Temporal patterns in proportion of whole seeds

There are differences between species in the patterns of proportion of whole seed in soil samples. *Wedelia asperrima* and *T. zeylanicum* were consistently high, in contrast to *C. hubbardiana* and *P. lacerosus.* Both *Wedelia* and *Trichodesma* are known to produce toxic compounds, and seeds of *T. zeylanicum* are known to be poisonous to vertebrates (Everist 1974); such compounds may provide chemical defence against soil micro-organisms. The proportion of whole seeds of the annual grass *C. hubbardiana* (Table 9.16) corresponds with similar data for annual grasses from northern savanna woodlands (Dostine *et al.* 2001). The dominant annual grass (*Sorghum* spp.) in these woodlands has a transient seed bank; seed numbers are depleted by germination and are replenished by seed fall after a highly predictable wet season. The life history strategies of annual grasses in more variable climates might be expected to differ, but the characteristics of seed dormancy, seed germination and seed production in *C. hubbardiana* have not been described.

9.4.4 Relationship between patterns of seed abundance and food data

Both *Wedelia asperrima* and *Trichodesma zeylanicum* share similar patterns of abundance. Seed of both is held on the plant until achenes of *W. asperrima* drop from the senescing floral cup, or nutlets of *T. zeylanicum* dehisce from the senescent fruit. Consequently there is a lag of months between flowering, seed set and seed availability to ground foraging birds. The pattern of abundance of *P. lacerosus* seed in soil samples is mirrored in the food data (Chapter 7): there is rapid decline after prominence in the June 2006 sample. The patterns of abundance in the food and on the soil surface suggest that seed is rapidly depleted by consumption or becomes unavailable by burial or subsidence in small cracks in the soil surface. Seed of *P. lacerosus* matures early in the season and is shed beneath the plant: the relative low density of *P. lacerosus* at all times throughout the study suggests that birds concentrate their feeding efforts in the vicinity of individual plants with a localised high density of seed.

9.4.5 Consequences of resource variability for Flock Bronzewing Pigeons

The consequences of the decline in food resources for Flock Bronzewing Pigeons might include a requirement for increased time spent foraging, more extensive searching, expansion of dietary niche or emigration from the area. Activity budgets were not recorded, and movement data is insufficient to measure seasonal differences in distance travelled during foraging. Dietary habits do vary between years, with seed of *Chionachne hubbardiana* being more prominent in crop contents of sampled birds in the mid-late dry season in 2007 than 2006, in contrast to the pattern of abundance of seeds reported here. Temporal variation in the abundance of Flock Bronzewing Pigeons on Helen Springs Station was quantified by a limited program of standardised counts of numbers visiting bores (Appendix 1). These data support general observations of an exodus during or after the wet season of 2006/07, and is consistent with the results of population monitoring elsewhere in the region. Numbers of Flock Bronzewing Pigeons recorded at bores on Alexandria Station in the eastern Barkly region varied between years consistent with variation in rainfall (Appendix 2). Pigeons were still present, though in low numbers, at both sites in both 2006 and 2007 despite the decline in seed density in 2007. Further, pigeons were known to be present at both sites in late 2005, a year of exceptionally low rainfall and presumably negligible seed production. Food resources during such poor years are unknown but presumably include ungerminated seed of ephemeral plants produced during the previous growing season. Clearly, further studies are required of resources used at these times, and factors determining the production and longevity of seed available to granivorous birds such as Flock Bronzewing Pigeons.

9.5 SUMMARY OF FINDINGS AND CONCLUSIONS

Patterns of resource availability in Mitchell grasslands were examined using satellite-based data on plant productivity, data on plant community composition, and data on soil seed abundance. Estimates of GPP (gross primary productivity) varied seasonally and between years in accord with rainfall patterns. The 2005/06 growing season was preceded by a well below average year, and extended into the dry season following late wet season rainfall. Both factors may exert important influences on the composition of plant communities, and the abundance of seed available to granivorous birds.

Spatial and temporal patterns in plant community structure in Mitchell grasslands were examined in years of contrasting rainfall pattern. Rank cover of all plant species was estimated in 35 plots in open grassland in the early dry season of 2006 and 2007. One hundred and twenty one plant taxa were identified; including 114 taxa in 2006 and 102 taxa in 2007. Plant species richness per plot differed significantly between years: the mean number of species per sites was 26.5 in 2006 and 22.1 in 2007. Inter-annual differences in floristic composition were analysed by both multivariate and univariate statistical methods. These methods yielded evidence that 14 taxa declined in abundance between years, and 7 taxa increased in abundance between years. Most of the taxa that declined in abundance were annual forbs; most of the taxa that increased in abundance were perennial forbs or grasses. Seven of the declining species and one of the increasing species are food plants of the Flock Bronzewing Pigeon.

Modelling of the temporal patterns of abundance of seed of four key food plants of the Flock Bronzewing Pigeon revealed differences between floristic groups. Seed numbers were higher in the aftermath of a higher than average wet season, and were diminished after an average wet season, after partial failure of seed production. Species differed in the proportion of whole seed present in the soil seed bank.

The consequences of the decline in food resources for Flock Bronzewing Pigeons might include requirement for foraging time, more extensive searching, expansion of dietary niche, or emigration from the area.

Chapter 10: MOVEMENTS OF FLOCK BRONZEWING PIGEONS. RESULTS FROM SATELLITE TELEMETRY

10.1 INTRODUCTION

Satellite telemetry has been widely employed in studies of avian migratory connectivity (Fuller *et al.* 1995, Webster 2002), especially in northern hemisphere waterbirds and raptors. Transmitting devices are now sufficiently miniaturised to be deployed on medium-sized organisms such as small waterfowl (Roshier *et al.* 2008), flying foxes (Tidemann and Nelson 2004), and pigeons (Casazza and Overton 2008). In the Australian rangeland context, satellite telemetry and remote sensing provide the capacity to address questions on how organisms interact with landscapes and resources across large spatial scales. They provide powerful tools for the development of understanding of the phenomenon of long-distance movement, habitat connectivity at large spatial scales, and the conservation management needs of dispersive species. To date, satellite telemetry has been deployed successfully to study movement behaviour of the Grey Teal *Anas gracilis* (Roshier *et al.* 2006) and the Australian Bustard *Ardeotis australis* (Ziembicki 2009). In northern Australia, radio-telemetry has revealed patterns of habitat use in frugivorous pigeons moving between rainforest patches (Price 1998), and seasonal patterns of home range size in a granivorous pigeon in savanna woodland (Fraser 2000). There have been no previous attempts to employ satellite telemetry to examine habitat use or movements of Flock Bronzewing Pigeons, or any other columbid species in Australia, and as such this study represents a trial to guide further studies. This chapter asks the following questions:

(1) Can satellite telemetry be used to describe the movement patterns of the Flock Bronzewing Pigeon?

(2) What are the short-term movement patterns of the Flock Bronzewing Pigeon, and how do they relate to rainfall and plant productivity?

10.2 METHODS

Prior to deployment of satellite transmitters on wild birds, three separate trials were conducted to assess efficacy of methods of handling and transmitter attachment. Firstly, domestic homing pigeons *Columba livia* were used to conduct trials of attachment of dummy transmitters on free-flying pigeons. The dummy transmitter was constructed of perspex and attached with a teflon ribbon harness. The tagged bird flew in formation with the flock without apparent ill-effects, and the harness and package were removed on return of the bird. Secondly, captive Flock Bronzewing Pigeons were used to trial handling procedures and two harness designs. These birds are held in a small landscaped display enclosure at the Territory Wildlife Park and are not able to fly freely. Birds were monitored for abnormal behaviour by park staff over several days. Two harness designs were used: firstly a design constructed of teflon ribbon, and a design constructed of 5mm flat elastic ribbon. The teflon harness could be custom-fitted to the individual bird but the handling process was time-consuming and difficult; the pre-sewn elastic harness could not be adjusted but the required time for handling was considerably less, and was considered a better option for field use. Thirdly, four wild Flock Bronzewing Pigeons were captured in the field at Helen Springs Station and tagged with 5.5 g VHF radio-transmitters and monitored during twice-daily visits to a watering point. Transmitters were glued on the central upper back after clipping body feathers. Over the following days the presence of transmitter signals was detected using an Advanced Telemetry Systems receiver-scanner and yagi directional antenna at the tagging point as birds gathered to drink in the morning and evening. One bird was detected at the tagging point over the following three days; a second bird was detected only on the following day after tagging; the remaining two birds were not detected after tagging. Individual birds were captured on different days, and not all birds were monitored for the same period. The fate of tagged birds was unknown though it was assumed that transmitters dropped from the birds within days and there were no long-term ill-effects. These trials provided some assurance that capture and handling procedures were satisfactory and that risks to individual birds were minimised.

Flock Bronzewing Pigeons were captured using traps of nylon leg snares attached to rubber strips which were fixed in place using small metal pegs. Individual traps were placed to intercept birds as they approached water to drink and were deployed as described in Appendix 3. Birds were removed on capture and processed or released immediately. During the study two handling procedures were employed. All birds released with VHF transmitters and at least three birds fitted with satellite transmitters (Platform Transmitting Terminals or PTTs) were processed at the capture site, wore black cloth hoods during handling, had no body measurements taken, and were released at the capture site (handling method 1). The remainder were placed in cloth bags and carried to a nearby field vehicle to be processed and released (handling method 2). Trapped individuals of non-target species including Magpie Lark *Grallina cyanoleuca*, Galah *Eolophus roseicapillus*, Australian Pratincole *Stiltia isabella* and Banded Lapwing *Vanellus tricolor* were released unharmed.

Miniature solar-powered satellite transmitters (9.5 g solar PTT-100) were purchased from Microwave Telemetry Inc. Transmitters were programmed to transmit for 10 hours, and then switch off for the next 48 hours to allow battery recharge. Signals from individual transmitters are detected and processed by the Argos satellite system; transmitter position is calculated using the frequency shift of receiving satellites using the Doppler principle. Positional data from Argos are coded with an accuracy location class. Location class 1 has an accuracy of 500-1,500 m, location class 2 has an accuracy of 250-500 m and location class 3 has an accuracy of 0-250 m (CLS 2008). Data from all location classes were used in this study. Transmitters weighed 9.5 g and constituted less than 4% of the body weight of the study species, within the recommended maximum transmitter load of 5%. Microwave Telemetry intends to produce a 5 g version of this transmitter in 2009. Satellite transmitters were attached with a harness to seven individual birds. All birds were trapped at turkey nest dams on Helen Springs Station (birds 1-4 at bore 4, latitude 18.116°S longitude 134.439°E; birds 5-7 at bore 9 on latitude 18.343°S longitude 134.436°E).

For each tagged bird the time since tagging in days, and the distance moved from the original tagging point in kilometres was calculated. Daily rainfall data for the period in which transmitters were deployed were provided by G. Murrell of Helen Springs Station.

Position data were overlain on habitat maps at two different scales: the 1:1,000,000 Northern Territory vegetation map (Wilson *et al.* 1991), and 1:100,000 land unit mapping of individual pastoral properties (Grant 2003, Edgoose and Lehman 1996). Land units are subjective and do not correspond between mapping projects. Position points were buffered by the maximum expected error for each location class using ArcGIS (ESRI 2004): data are presented for both buffered and unbuffered points.

10.3 RESULTS

All but one of the PTT tagged birds either perished within days of release or the PTT failed and the immediate fate of the bird is unknown (Table 10.1). It is clear that Flock Bronzewing Pigeons are sensitive to handling stress, and may suffer capture related trauma known as capture myopathy which may render them vulnerable to predation. Capture myopathy is an acute degeneration of muscle resulting from intense muscular exertion and trauma caused by restraint and transport (Hulland 1985). Two PTTs were recovered on the ground in the vicinity of raptor nests, at least one of which was occupied by a nesting pair of Wedge-tailed Eagles *Aquila audax*.

Table 10.1 Dates of PTT attachment, estimated displacement and survival of tagged Flock Bronzewing Pigeons.

Bird #	Date of PTT attachment	Max. estimated displacement (kms)	Estimated survival (days)	Handling method	Fate of bird
1	3/08/2006	18.6	7	1	Perished. PTT recovered at raptor nest.
2	27/08/2006	236.9	205.4	1	Presumed perished. PTT not recovered.
3	28/08/2006	2.2	0.2	1	PTT malfunction. Immediate fate unknown.
4	27/09/2006	21.1	3.3	?	PTT malfunction. Immediate fate unknown.
5	9/07/2007	2	0.4	2	Perished. PTT recovered at raptor nest.
6	14/09/2007	2	2.5	2	Presumed perished. PTT not recovered.
7	17/09/2007	3.5	2.5	2	Presumed perished. PTT not recovered.

There is scant evidence to discriminate reasons for failure from success. However, both individuals surviving for at least one week were caught and released on days with relatively low maximum temperatures, and with relatively low maximum temperatures over the following few days (Figure 10.1). This is consistent with known risk factors associated with the capture and handling of trauma prone species.

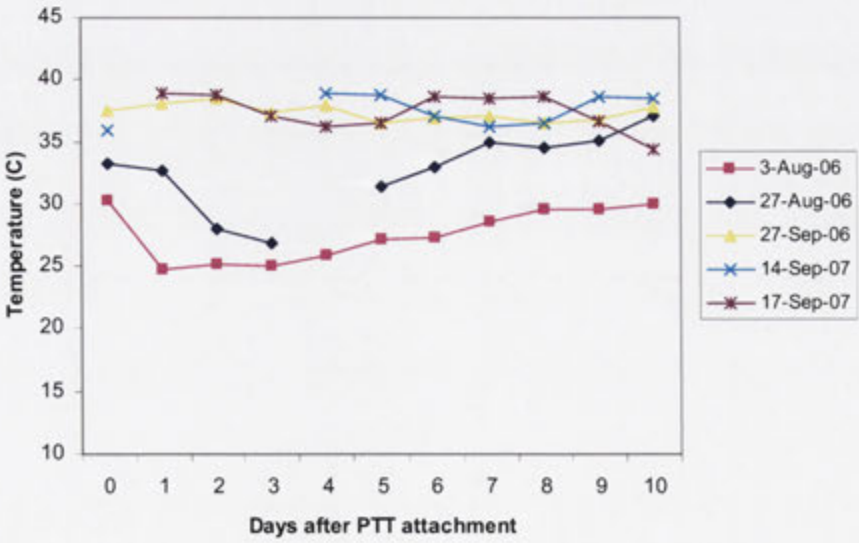


Figure 10.1 Maximum daily air temperature in 10 days following attachment of PTT to five Flock Bronzewing Pigeons.

Air temperature recorded at Brunette Downs Station. The most successful bird was captured on 27th August 2006; the next most successful was captured on 3rd August 2006.

Bird number 2 was trapped and tagged with PTT #57614 on 27th August 2006, and was tracked continuously for more than 200 days until mid-late March 2007, after which the PTT continued to operate for a total of 386 days. For most of this period the bird remained in the vicinity of two watering points in adjacent paddocks on Helen Springs Station and the adjacent Eva Downs Station (Figure 10.2). The average distance from the origin (using only location class 3 position data) was 4.9 km (range 0.8-7.1) in the period prior to mid-January. After mid-January the bird left the area and moved in stages to an area mapped as bluebush swamp (1:1,000,000 scale mapping) on Alroy Downs Station, a net displacement of approximately 230 km (Figure 10.3). Departure coincided with significant rainfall (222 mm) in the area in the preceding five days (Figure 10.4). Departure also coincided with a period of relatively low air temperature.

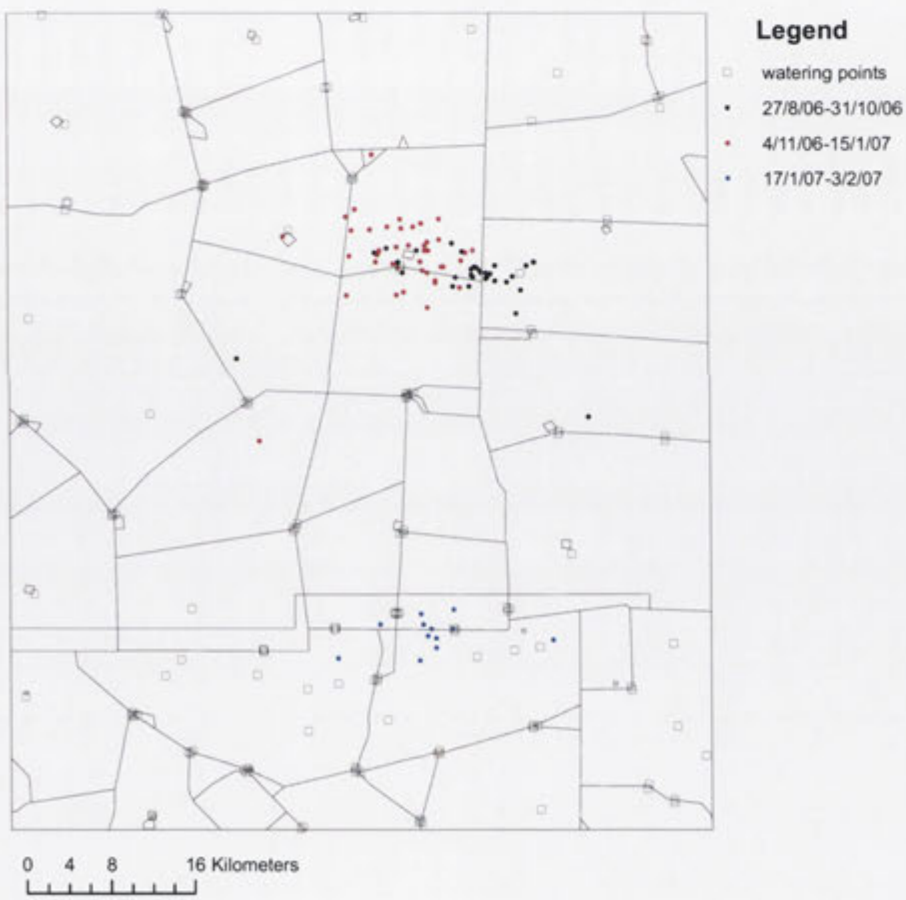


Figure 10.2 Position fixes for Flock Bronzewing Pigeon tagged with PTT #57614, in three intervals from date of capture.

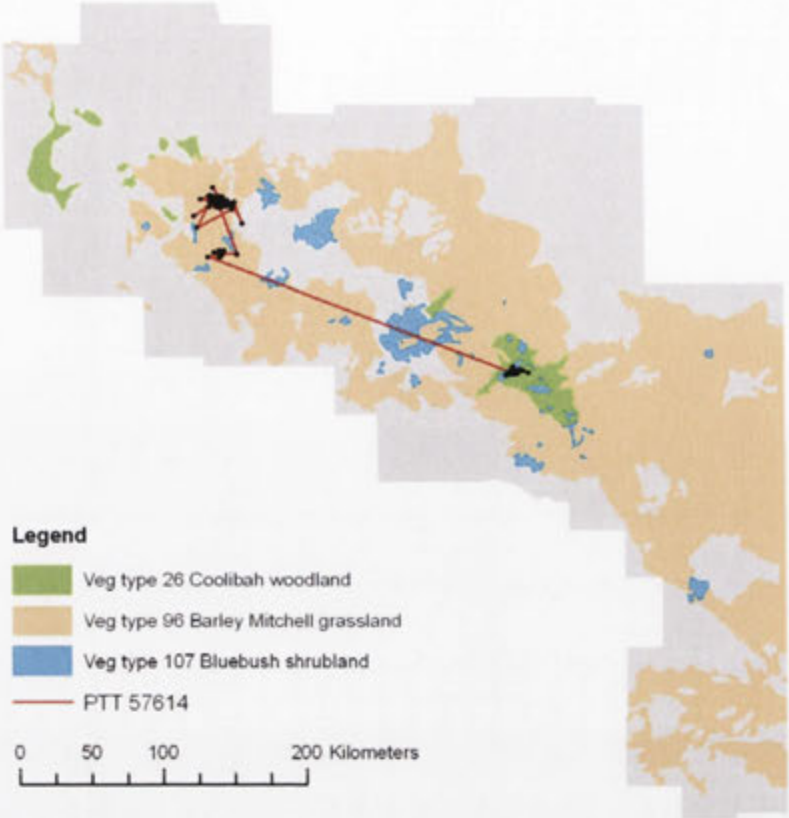


Figure 10.3 Movements of PTT tagged Flock Bronzewing Pigeon.

Map shows selected vegetation units from 1:1,000,000 NT vegetation map within Barkly pastoral district.

Table 10.2 Description of vegetation units intersected by estimated positions of tagged Flock Bronzewing Pigeon from 1:1,000,000 scale map of vegetation of the Northern Territory (Wilson *et al.* 1991).

Number of position fixes in each vegetation unit for both unbuffered and buffered data. Percentage data shown in brackets.

Veg. unit	Description	Unbuffered data	Buffered data
26	*Eucalyptus microtheca* (Coolibah) low-open woodland with *Eulalia aurea* (Silky Browntop), *Astrebla* (Mitchell Grass) grassland understorey.	3 (2.8)	1 (1.2)
28	*E. microtheca* (Coolibah) low open-woodland with *Chenopodium auricomum* (Bluebush) sparse-shrubland understorey.	1 (0.9)	1 (1.2)
39	*E. pruinosa* (Silver Box), *Lysiphyllum cunninghamii* (Bauhinia) low open-woodland with hummock/tussock grassland understorey.	12 (11.0)	2 (2.5)
96	*Astrebla pectinata* (Barley Mitchell grass) grassland.	72 (66.1)	64 (79.0)
107	*Chenopodium auricomum* (Bluebush) low open-shrubland with ephemeral grassland understorey	21 (19.3)	16 (16.0)
Total		109	81

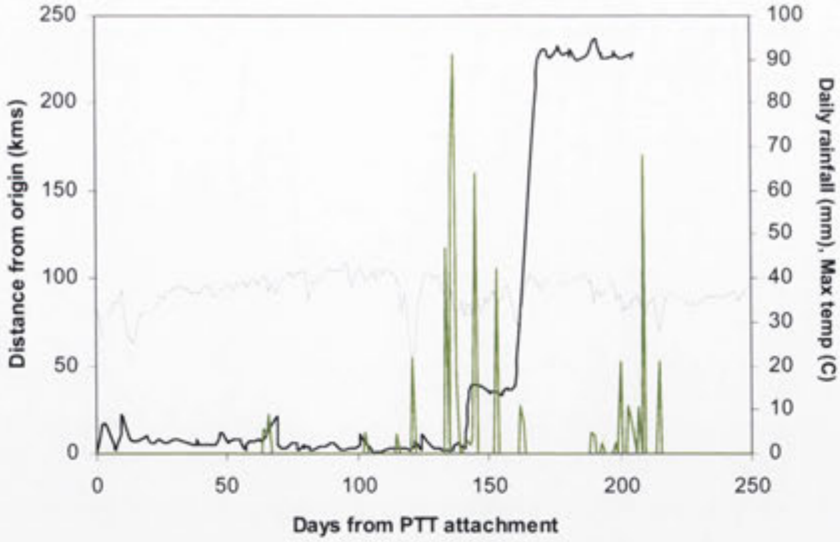


Figure 10.4 Relationship between distance moved from origin and time after PTT attachment.

Daily rainfall (mm) recorded at Helen Springs Station, and maximum daily temperature recorded at Brunette Downs Station. PTT #57614 was attached on 27th August 2006.

Table 10.3 Description of land units intersected by estimated positions of tagged Flock Bronzewing Pigeon from 1:100,000 scale map of land units of Helen Springs Station (Grant 2003).

Number of position fixes in each land unit for both unbuffered and buffered data. Percentage data shown in brackets.

Land unit	Description	Unbuffered data	Buffered data
3.2	Level plain with red earths supporting a mid-high open woodland of northern bloodwood and variable barked bloodwood over a groved tall open shrubland of turpentine over a mid-high open hummock grassland of hard spinifex.	7 (10.4)	
3.3	Level plain with clayey soils supporting a mid-high sparse tussock grassland of Australian dropseed and feathertop wiregrass.	1 (1.5)	
3.6	Level plain with scattered melonhole gilgai. Clayey soils support scattered coolibah over a low sparse tussock grassland of annual grasses on the shelf and a tall open tussock perennial grassland in the gilgai.	1 (1.5)	
4.1	Gilgaied plain with clay soils supporting a mid-high sparse tussock grassland of annual grasses on the gravelly shelf and a very tall open grassland of silky browntop in the gilgai.	2 (3.0)	
4.2	Gilgaied plains with Barley Mitchell and ribbon grasses.	8 (11.9)	
4.3	Plains with linear gilgai. Clay soils supporting a low sparse tussock grassland of annual grasses on the shelf and a tall sparse tussock grassland of Mitchell grasses in the gilgai.	14 (20.9)	
5.1	Alluvial plain occasionally with small crabhole gilgais. Heavy, grey, clay soils supporting a tall open tussock grassland of Barley Mitchell grass.	5 (7.5)	
5.2	Alluvial plain with heavy, grey, clay soils supporting a mid-high open tussock grassland of annual grasses (red Flinders grass).	10 (14.9)	
5.3	Alluvial plain with heavy, grey, clay soils supporting a mid-high open tussock grassland of Barley Mitchell grass (*A. pectinata*) and Hoop Mitchell grass (*A. elymoides*).	17 (25.4)	
6.1	Ephemeral swamp, with heavy, grey clay soils supporting a tall open chenopod shrubland of Queensland bluebush over annual verbine and pepper grass.	1 (1.5)	
6.3	Ephemeral swamp, with heavy, grey clay soils supporting a mid-high open woodland of coolibah over a very tall sparse tussock grassland of swampgrass.	1 (1.5)	
Total		67	0

Table 10.4 Description of land units intersected by estimated positions of tagged Flock Bronzewing Pigeon from 1:100,000 scale map of land units of Alroy Downs Station (Edgoose and Lehman 1996).

Number of position fixes in each land unit for both unbuffered and buffered data. Percentage data shown in brackets.

Land unit	Description	Unbuffered data	Buffered data
2.1	Gilgaied downs country with Mitchell grass pastures.	1 (4.2)	
4.1	Alluvial plain with Flinders grass near drainage lines and swamps.	1 (4.2)	1 (25.0)
4.2	Broad, flat alluvial plain with native millet, pepper grass and Flinders grass pastures.	2 (8.3)	1 (25.0)
4.4	Islands in the Playford River floodplain with button and Flinders grasses.	1 (4.2)	
5.2	Swamp margins with sparse bluebush over annual grasses.	12 (50.0)	1 (25.0)
5.3	Drainage margins with Flinders grass, native millet and sparse bluebush.	5 (20.8)	1 (25.0)
6.1	River channel country along the Playford River with lignum over annual grasses.	2 (8.3)	
Total		24	4

The majority of estimated positions of PTT #57614 (79.0% of corrected data) were located in vegetation unit 96 of the 1:1,000,000 vegetation map of the Northern Territory, described as *Astrebla pectinata* grassland (Table 10.2). Positions within vegetation unit 107 (*Chenopodium auricomum* low open-shrubland) were only recorded after 12th February 2007, and comprise >90% of data points at this time. Errors associated with Argos position fixes eliminate most of the buffered data points and little can be inferred from the fine scale land unit mapping. However, the majority of uncorrected data points in the Helen Springs area (n=17, 25.4%) occur within land unit 5.3, consisting of open tussock grassland of *Astrebla pectinata* and *A. elymoides* (Table 10.3). This is consistent with the results from habitat studies reported in Chapter 8. In addition, the majority of uncorrected data points in the Alroy Downs area occur within land units 5.2 (n=12, 50.0%) and 5.3 (n=5, 20.8%), described as 'swamp margins with sparse bluebush over annual grasses', and 'drainage margins with Flinders grass, native millet and sparse bluebush' respectively (Table 10.4). This suggests that the fringes of bluebush swamp areas may be important habitat, rather than large homogeneous patches. This is consistent with field observations of Flock Bronzewing Pigeons in the late wet season, as well as results of dietary analyses (Chapter 7).

10.4 DISCUSSION

This study is the first attempt to employ satellite telemetry to study movement patterns of Flock Bronzewing Pigeons. The study demonstrated that satellite telemetry can be used to track movements of this species, but that further work is required to refine methods to minimise hazards to tagged birds. The species appears to be prone to capture and handling trauma, which may lead to impairment and increased risk of predation. The physiological syndrome known as capture myopathy is a common contributor to mortality in wildlife studies, and has been diagnosed in several bird families including Otitidae (Marco *et al.* 2006, Ponjoana *et al.* 2008), Gruidae (Windingstad *et al.* 1983), Phasianidae (Abbott *et al.* 2005, Nicholson *et al.* 2000, Hofle *et al.* 2004), Anatidae (Dabbert and Powell 1993) and Charadriidae (Minton 1993). Precise causes are unclear, but related to elevated levels of lactic acid as a response to intense muscular activity (Wobeser 1997). Risk factors include over-exertion during periods of high ambient temperature (Nicholson *et al.* 2000, references cited in Hofle *et al.* 2004). Capture myopathy was not diagnosed by autopsy of recovered birds in this study, but is considered to be a likely contributing factor to mortalities. Solutions to this problem may include avoidance of high risk weather conditions (Nicholson *et al.* 2000), refinement of trap design to minimise over-exertion, minimising handling time, rehabilitation of afflicted birds (Rogers *et al.* 2004) or treating muscular damage with an injection of vitamin E and selenium (Abbott *et al.* 2005). Suggested refinements to capture and handling procedures are summarised in Table 10.5.

Table 10.5 Suggested procedures for capturing, handling and attachment of transmitters to Flock Bronzewing Pigeons.

Field procedures
Trapping
Construction
Built-in elasticity in trap design to minimise muscular over-exertion, and risk of capture myopathy.
Placement
Position traps at sufficient distance from damp edge to avoid feather contamination.
Maintain direct and continuous vision of traps to allow rapid response and eliminate risk of predation.
Weather conditions
Avoid trapping on days with max temp >35°C, preferably overcast with some rain in area.
Handling
Remove birds immediately after capture by snares.
Hood birds immediately.
Minimise handling time.
Investigate suitable field anaesthesia techniques.
PTT attachment
Construct harness to allow rapid attachment to bird.
Use custom-built harnesses to match body size of bird, rather than attempt body size adjustment of harness in field.
Release methods
Develop remotely triggered release box with 'fall-away' sides to minimise human-induced stress.

There are other explanations for the lack of success. It may simply be that the presence of the transmitter caused abnormal behaviour, or that the transmitters identified tagged birds as different, with this difference causing predators to target such individuals. Saunders (1988) found that the rate of return of Carnaby's Cockatoos *Calyptorhynchus funereus latirostris* to breeding areas was less for patagial-tagged than leg-banded individuals, and that the difference was probably due to avian predation. Saunders (1988) speculated that the reflective glint of the tags may have attracted the attention of Wedge-tailed Eagles. The reflective surface of the solar panel on transmitters borne by Flock Bronzewing Pigeons may similarly have attracted the attention of avian predators.

For the single bird for which this study provided long-term data, there is evidence that rainfall initiated a substantial movement response. This result is consistent with other data from population indices (Appendix 2) and community-based surveys, and also consistent with observations on other nomadic Australian birds (Frith 1962, Roshier *et al.* 2008). Nomadism is a viable strategy only when extreme environmental conditions are sufficiently frequent and unpredictable to maintain movements to high resource patches, or to maintain dispersal away from low resource patches (Dean 1997). Flock Bronzewing Pigeons must contend with seasonal depletion of resources by seed germination during the wet season, as well as large fluctuations in seed density from year to year. Survival depends on making correct decisions on the timing of departure from ephemeral resource patches, and an ability to find another high resource patch. Flock Bronzewing Pigeons appear to use rainfall as a cue for dispersal; presumably the benefits of dispersal at this time outweigh the costs of remaining sedentary. The observation that the departure of bird #57614 coincided with significant local rainfall and a period of relatively low air temperature accords with observations on movement behaviours of Grey Teal. Most extended flights in this species occurred at night and at low ambient temperatures (Roshier 2009), presumably to avoid overheating during intense bouts of muscular exertion (Engel *et al.* 2006).

The focal bird in this study shifted habitat from open Mitchell grassland to a complex of habitats featuring Queensland bluebush *Chenopodium auricomum.* Bluebush swamps are floristically distinct from the surrounding perennial tussock grasslands (Brock 2000). There is evidence from dietary data, albeit limited, that seed of early seeding perennial herbs such as *Commelina tricarinata* may be important in these habitats. This pattern of seasonal habitat shifts and reliance on early seeding perennial plants is observed in other granivorous birds in northern Australia (Dostine *et al.* 2001, Garnett and Crowley 1994). The timing and extent of serial movement steps between habitat patches by individuals of nomadic species is of considerable interest (Roshier *et al.* 2008), but remains to be adequately addressed in the Flock Bronzewing Pigeon.

10.5 SUMMARY OF FINDINGS AND CONCLUSIONS

Six of seven attempts to deploy satellite transmitters on Flock Bronzewing Pigeons failed due to either transmitter failure or bird mortality within days of capture and release. Reasons for failure are unknown but may include abnormal behaviour induced by the attachment of the transmitter, and capture myopathy from muscular over-exertion; both of which may render individuals vulnerable to predation. Solutions may include refinement of attachment methods, minimising muscular exertion during trapping and handling, and minimising handling time.

The movements of a single male Flock Bronzewing Pigeon were tracked by satellite telemetry from late August 2006 to late March 2007, over a period of more than 200 days. During this period the bird remained within an average radius of <5 km of the tagging point until substantial rainfall triggered a displacement of approximately 230 km, and a shift in habitat from open Mitchell grassland to a complex of habitats featuring Queensland bluebush *Chenopodium auricomum.* This result accords with field observations of foraging habitat during the late wet season, and with results of dietary analyses.

Chapter 11: PATTERNS OF ABUNDANCE OF FOOD PLANTS OF THE FLOCK BRONZEWING PIGEON. EFFECTS OF GRAZING AND INTER-ANNUAL VARIATION

11.1 INTRODUCTION

The term Mitchell grasslands is applied to a vegetation type consisting of extensive treeless grasslands on fine-textured cracking clay soils dominated by the perennial tussock-grass genus *Astrebla*. These grasslands occur in a broad arc across northern Australia within the 250-550 mm rainfall isohyets and cover 320,000 km^2 mostly within the Northern Territory and Queensland (Orr and Holmes 1984). Mitchell grasslands provide an important grazing resource for the pastoral industry: in Queensland they support 45% of the State's sheep and 10% of the cattle (Phelps and Bosch 2002). Most ecological research in these grasslands relate directly to the effects of grazing and drought on aspects of animal production rather than conservation biology or biodiversity.

Grazing is the dominant land use over 60% of the land area of Australia (Wilson 1990). Grasslands of northern Australia have been exposed to an uninterrupted history of grazing since occupation of grazing lands in the late 19^{th} century: the extent of change due to introduced herbivores in grassy ecosystems can never be fully known, except for rare glimpses provided by grazing refugia (Fensham and Skull 1999). The open black-soil plains of northern Australia provide no such refugia for Mitchell grass communities, and there are few, if any, protected fragments which do not have a history of past grazing. Mitchell grass communities are regarded as resilient disclimax communities maintained by moderate grazing as a surrogate for the pre-grazing disturbance regime of intermittent disturbance from fire and low intensity macropod grazing (Everist and Webb 1975). Fire frequency in grasslands has been reduced by removal of grassy fuel by stock and fire suppression (Wilson 1990), though recorded evidence of Aboriginal burning practices in Mitchell grasslands is not substantial (Fensham 1997).

Empirical studies in Mitchell grasslands have focussed on the response of tussock basal area to variation in rainfall and grazing pressure (Orr 1980, Orr *et al.* 1986, Orr and Phelps 1994). Perennial grass tussocks form the basic unit of the pasture and occupy a basal area of 4-5% of the pasture under favourable seasonal rainfall (Orr and Holmes 1984); the remainder may be occupied by an interstitial flora of annual and ephemeral grasses and forbs, and other perennial grasses, which vary in composition depending on the dominance of summer rainfall and recent rainfall history (Orr 1981, Foran and Bastin 1984). During years of favourable summer rainfall the basal area and biomass of *Astrebla* spp. increase and these plants out-compete ephemeral interstitial plants for moisture and other resources leading to declines in the latter's relative abundance. Conversely, during below average rainfall periods the proportion of annual grasses and forbs increases due to competitive release. Further, seedling recruitment has been shown to be dependent on the intensity of competition from annual grasses, and sensitive to the sequence of rainfall events within and between years (Orr 1991). Studies on the long-term effects of grazing on *Astrebla* dominated communities are largely confined to unreplicated studies of paired sites with a previous history of grazing and no data on prior condition (e.g. Hall and Lee 1980, Foran and Bastin 1984, Orr and Evenson 1991). Increased yields of the annual grass *Iseilema* spp. were reported under heavy cattle grazing relative to light sheep grazing (Hall and Lee 1980), and in cattle grazed areas relative to an ungrazed exclosure (Foran and Bastin 1984). Overall, these studies suggest that there are complex interactions between pasture condition, rainfall patterns and the timing and intensity of grazing. Light or moderate grazing levels are required to avoid degradation of perennial grass communities during drought (McKeon *et al.* 2004). The consequences of such degradation include replacement by annual grassland and loss of productive capacity (Davidson 1954, Orr and Holmes 1984).

The study of Fisher (2001) provides a biogeographic context for Mitchell grass communities in the Northern Territory and assessment of the impacts of grazing on individual species by inferences from the patterns of occurrence across grazing gradients, and by cross-fence comparisons of the patterns of occurrence in grazed versus reserved areas. Grazing had no pronounced effect on plant site richness. There were no effects of distance from water on total richness or richness of any plant type, and plant richness in areas of cattle removal were lower than grazed areas elsewhere in the landscape. Modelling identified individual species response patterns in relation to grazing pressure using distance to water as a surrogate for grazing pressure. Specifically, for the major food plants of Flock Bronzewing Pigeons, Fisher found an increaser type response for *Wedelia asperrima* (Asteraceae), and inconsistent responses for *Trichodesma zeylanicum* (Boraginaceae). There were no significant models for *Chionachne hubbardiana* (Poaceae) nor *Phyllanthus lacerosus* (Euphorbiacae).

Aside from the analyses of Fisher (2001) and broad-scale biogeographic analyses (Fensham *et al.* 2000), ecological data on these species is lacking. Anecdotal information from specimen notes of the Queensland Herbarium suggest that the annual grass *Chionachne hubbardiana* was favoured by stock; that *T. zeylanicum* induced symptoms of poisoning in horses; and that *Wedelia asperrima* could have weedy characteristics (Table 11.1). These notes are consistent with the few comments in the available literature. Both *W. asperrima* and *T. zeylanicum* have been reported as being poisonous (Everist 1974). *Wedelia asperrima* is noted to respond well to summer rains and is often associated with deteriorating Mitchell grass country (Milson 2000).

Table 11.1 Notes from selected specimen records of food plants of Flock Bronzewing Pigeons from Queensland Herbarium.

Species	Date	Ref no	Comments
Chionachne hubbardiana	23-Apr-53	280258	Good feed and sought by cattle. It seeds quickly and dies off quickly.
Chionachne hubbardiana	28-Jan-66	280266	On brown clay in grassland with *Astrebla lappacea* dominant. Reputed to be heavily grazed by horses.
Chionachne hubbardiana	11-May-33	280265	Seems to be quite a useful fodder.
Trichodesma zeylanicum latisepalum	25-Feb-57	25477	On natural pasturage. Horses affected, first symptoms noted 7 months ago, movement of limbs uncoordinated, muscles stiff, animals flounder and stumble.
Wedelia asperrima	16-May-47	272018	Overgrazed *Astrebla* grassland.

There is considerable interest in options for grazing management in northern Australia. Pastoralists seek to increase stocking rates by making more efficient use of available pasture by infrastructure development and intensive herd management (Petty 2007). There is also an interest in quantifying the implications for biodiversity of grazing management options. In this chapter I focus on data derived from the two main recent studies on the effects of grazing management on biodiversity in Mitchell grass habitats in northern Australia. This chapter addresses the following questions:

(1) What are the broad-scale habitat relationships of known food plants of the Flock Bronzewing Pigeon?

(2) How do patterns of occurrence of these species vary between years and between different grazing treatments?

(3) Is there evidence of an effect of grazing on the patterns of occurrence of these species in grazed and ungrazed sites within a single treatment paddock?

11.2 METHODS

11.2.1 Pigeon Hole grazing experiment

Data on the abundance of key food plants were obtained from two grazing experiments conducted in the Victoria River District in the Northern Territory. The first grazing experiment was conducted at Pigeon Hole Station. The research project was a collaboration between CSIRO Sustainable Ecosystems, Biodiversity Conservation Unit of NRETA, and Heytesbury

Pastoral Company, with funding assistance from Meat and Livestock Australia and the Tropical Savannas Cooperative Research Centre. The project sought to address the production benefits, and consequences for biodiversity, of different grazing regimes. These included variation in pasture utilisation rates, variation in density of watering points, cell grazing and wet season spelling. Five levels of pasture utilisation were imposed (15%, 20%, 25%, 30% and 40%) by adjusting stocking rates at the start of the dry season in order to deplete a given proportion of standing forage during the following twelve months. There were two levels of variation in density of watering points: 1 and 3 km grazing radius. Cell grazing involves rotation of stock through small paddocks and is designed to optimise grass production. Wet season spelling involves rotational spelling of adjacent paddocks to provide sequential grazing relief during the wet season. Data on effects of watering point density, cell grazing and wet season spelling were not analysed in this study. Experimental treatments were unreplicated. Non-grazed sites were established in comparable environments within exclosures of various sizes and on neighbouring Gregory National Park. Sampling commenced in 2003 one year prior to the establishment of the trial grazing regimes, and data collection spanned the years 2003-2007. Pigeon Hole Station has had a long history of grazing prior to the establishment of the trial grazing regimes. Flock Bronzewing Pigeons were present in the study area, though not in large numbers, in May 2005 and were observed on other occasions throughout the study period.

The second grazing experiment was conducted at Mount Sanford Research Station by staff of the NT Department of Primary Industry and the Biodiversity Conservation Unit of the NT Department of Natural Resources, Environment, the Arts and Sport (NRETAS). Sampling was conducted using similar methods as the Pigeon Hole study in open black soil grasslands in years 2002, 2003 and 2006. The experiment involved four levels of pasture utilisation rates (13%, 23%, 39% and 47%). There were no exclosure treatments. There is no information on the presence of Flock Bronzewing Pigeons at the site, though the habitat is deemed to be suitable.

11.2.1.1 Patterns of plant productivity

Estimates of gross primary productivity (GPP mmol CO_2 m^{-2} day^{-1}) of the raingreen component of vegetation were derived from MODIS satellite imagery processed and provided by Dr S. Berry of the Fenner School of Environment and Society at the Australian National University. Methods of data acquisition and analysis are presented by Berry *et al.* (2007) and summarised in Chapter 6. Mean monthly GPP data per paddock was derived using ArcGIS (ESRI 2004) from 100 randomly selected points per paddock. GPP data were calculated for the pasture utilisation experimental paddocks on Pigeon Hole Station for the period 2000-2007.

11.2.1.2 Plant abundance data

Plant abundance data were collected under a program coordinated by Alaric Fisher of NRETAS within the Pigeon Hole project. Data were collected from 100 sites distributed between treatment paddocks and on adjacent areas of Gregory National Park. Sites consisted of 50 x 50 m plots: on each sampling occasion in the early dry season plant data were collected from within twenty 0.5 m^2 quadrats placed in a 4 x 5 grid. The cover of each plant species present within each quadrat was estimated using an eight rank scoring system as follows: 0 = none, 1 = 0-1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 7 = 95-100%. The mean cover per plot for each plant species was derived by averaging the mid-points of these cover ranks. Plant cover estimates for each species per quadrat were averaged to derive an average cover estimate for each species per site. The frequency of occurrence of each species per plot was calculated by summing the number of quadrats in which the species was recorded to be present. Data from the Mount Sanford grazing experiment were collected from 24 sites distributed between treatment paddocks. In 2002 and 2003 data were collected from within sixteen 0.5 m^2 quadrats placed in a 4 x 4 grid, in 2006 data were collected from within twenty 0.5 m^2 quadrats placed in a 4 x 5 grid. Mean cover per species and frequency of occurrence were calculated using methods described for the Pigeon Hole grazing experiment.

11.2.1.3 Variation in mean projected foliage cover

Data on mean percent projected foliage cover from the pasture utilisation paddocks on Pigeon Hole Station is presented to illustrate the range of variation in responses between years and grazing treatments for eight plant species, including three which make major contributions to total plant cover (i.e. the annual grass *Sorghum timorense*, an annual grass *Iseilema fragile* and the herbacious vine *Rhynchosia minima*), three food plant species (*Chionachne hubbardiana*, *Wedelia asperrima* and *Trichodesma zeylanicum*) and a congener of a major food plant species (*Phyllanthus maderaspatensis*), and an ephemeral herb (*Blumea tenella*).

11.2.1.4 Data analysis

Data analysis addressed three questions on the patterns of abundance of three known significant food plants of the Flock Bronzewing Pigeon. Analysis proceeded via several steps. Firstly I used multivariate techniques to examine the compositional similarity of plant communities using data from all 100 sites and all sampling occasions from the Pigeon Hole grazing experiment. The relative abundance and position in ordination space of three food plant species, and other relevant species, is shown graphically using bubble-plots overlying ordination coordinates. Multivariate analyses were conducted using the software program PRIMER version 6 (Clarke and Gorley 2006), with the Bray-Curtis dissimilarity measure and square root data transformation of mean cover data. Secondly, I used data on the frequency of occurrence of three food plant species from the pasture utilisation treatments to model the effects of annual variation and grazing using generalised linear modelling. Statistical analyses were conducted using the R software package (R Development Core Team 2008) using binomial errors and the categorical variables YEAR (2003, 2004, 2005, 2006 and 2007), UTIL_RATE (U15%, U20%, U25%, U30% and U40%) and SPECIES. Subsequent analyses were conducted for individual species. The response variable in analyses was the proportion of quadrats on each plot in which the species was present, and was created by binding two vectors using the function cbind in R, as follows: *y* < *cbind (Successes, Failures),* where *Successes* were the number of quadrats with the species present, and *Failures* the number of quadrats with the species absent (Crawley 2003). The number of sites in each treatment per year is shown in Table 11.2. Grazing treatments were unreplicated and interpretation of modelling results is confounded by pre-existing spatial differences unrelated to grazing pressure, and non-random placement of sites within heterogeneous experimental sites. Grazing effects might reasonably be inferred from a consistent linear response among levels of utilisation rate. Thirdly, I compared the frequency of occurrence of food plant species within grazing exclosures and ambient conditions within the most severe pasture utilisation treatment (U40%) using data from 2004-2007 and data from four ungrazed sites and seven grazed sites. Statistical analysis was conducted using binomial modelling as described above and the categorical variables YEAR (2004, 2005, 2006 and 2007) and GRAZE_TYPE (Grazed, Ungrazed exclosure).

Data from the Mount Sanford grazing experiment were analysed using similar methods as described above. Data on the frequency of occurrence of three food plant species were analysed using binomial errors and the categorical variables YEAR (2002, 2003 and 2006), UTIL_RATE (13%, 23%, 39% and 47%) and SPECIES. Subsequent analyses were conducted for individual species.

Models were assessed using the Akaike Information Criterion corrected for small sample size (AIC_c). Models were checked for over-dispersion using the Chi^2 test; where models were significantly over-dispersed, values of AIC_c were corrected for bias to calculate quasi-AIC_c ($QAIC_c$) using a variance inflation factor (Burnham and Anderson 2002) derived from the global model. The over-dispersion parameter c should generally be $1 \leq c \leq 4$ (Burnham and Anderson 2002). Where this was not the case, the analysis was abandoned. Further details on model selection are given in section 3.2.7.

Table 11.2 Numbers of sites in each level of pasture utilisation per year 2003-2007 in Pigeon Hole grazing experiment.

Year	U15%	U20%	U25%	U30%	U40%	Total
2003	5	5	6	8	7	31
2004	6	6	6	10	7	35
2005	6	6	6	10	7	35
2006	6	6	6	10	7	35
2007	6	6	6	10	7	35
Total	29	29	30	48	35	171

11.3 RESULTS

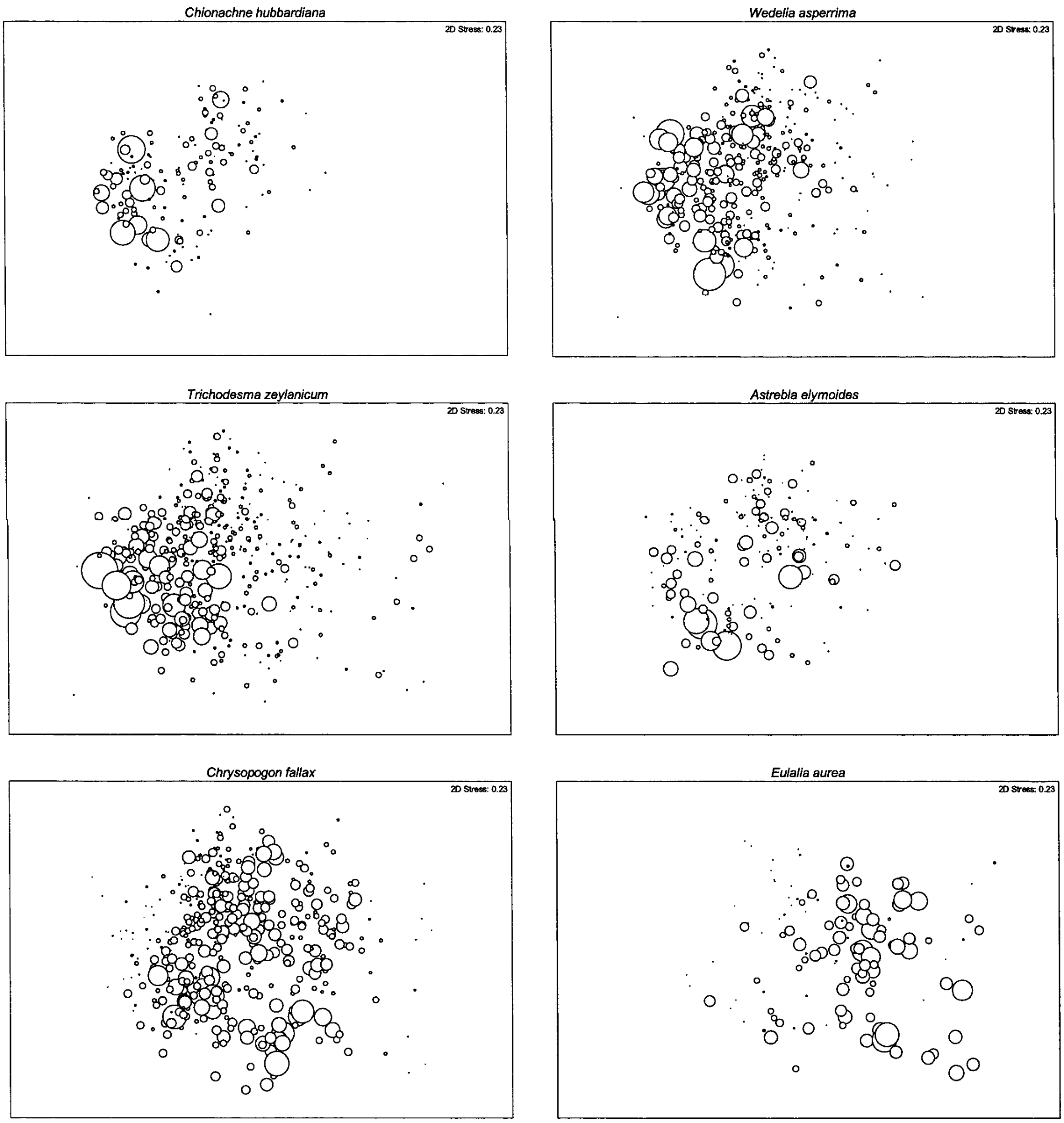
11.3.1 Broad-scale patterns of abundance of Flock Bronzewing Pigeon food plants

Analyses were conducted using three of the four food plants identified in dietary studies on Helen Springs Station in the Barkly Tableland and described in Chapter 7 of this thesis. One of these food plants, *Phyllanthus lacerosus* (Euphorbiaceae), was either not recorded, or was not distinguished from the commonly occurring related species *P. maderaspatensis.* In the Pigeon Hole study the annual grass *C. hubbardiana* was recorded at 56% of sites, on 31% of sampling occasions and within 3.4% of the total number of quadrats; in the Mount Sanford study *C. hubbardiana* was recorded at 71% of sites, on 67% of sampling occasions and within 22.4% of the total number of quadrats (Table 11.3). Both *W. asperrima* and *T. zeylanicum* were relatively more abundant than *C. hubbardiana* in the Pigeon Hole study; in contrast *C. hubbardiana* was more abundant in the Mount Sanford study and *W. asperrima* was less abundant. These patterns are consistent with the general observations that Pigeon Hole has been subject to more intense grazing than Mount Sanford, that *C. hubbardiana* may be a decreaser species under grazing, and that *W. asperrima* can increase under grazing pressure. All three species persist in grazed landscapes, and there is no evidence of extreme sensitivity to grazing.

Table 11.3 Frequency of occurrence of three food plant species at two study areas in the Victoria River District, Northern Territory.

	Pigeon Hole Station			Mount Sanford Station		
Taxa	No. of sites (%)	No. of site/years (%)	No. quadrats (%)	No. of sites (%)	No. of site/years (%)	No. quadrats (%)
Chionachne hubbardiana	56 (56)	143 (31)	314 (3.4)	17 (71)	48 (67)	279 (22.4)
Wedelia asperrima	87 (87)	347 (75)	1,150 (12.4)	13 (54)	35 (49)	83 (6.7)
Trichodesma zeylanicum	100 (100)	402 (87)	1,545 (16.7)	19 (79)	61 (85)	428 (34.3)
Total	100	462	9,240	24	72	1,248

Ordination plots of plant community data from the Pigeon Hole study demonstrates the differences in relative abundance of the three food plant species, and that all three species occupy a similar portion of the environmental envelope as represented by the ordination result (Figure 11.1). This portion is shared by the perennial tussock-grass *Astrebla elymoides*, and is distinct from the environmental space occupied by other perennial tussock grasses and the annual grass *Sorghum timorense*. This separation is probably related to landscape position and soil properties, with food plants favouring occasionally inundated sites with friable, black cracking clay soils.



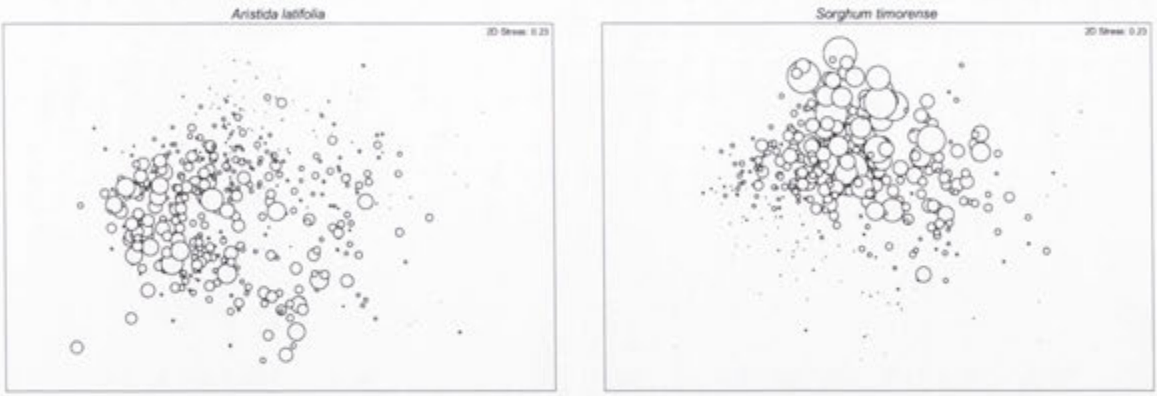


Figure 11.1 Bubble-plots of abundance of selected taxa using all site data from Pigeon Hole grazing project.

Three food plant species *Chionachne hubbardiana*, *Wedelia asperrima* and *Trichodesma zeylanicum* scaled identically, others with varying scaling. These species occupy similar portion of ordination space, distinct from perennial grasses *Chrysopogon fallax* and *Eulalia aurea* and annual grass *Sorghum timorense.*

11.3.2 Inter-annual patterns of plant productivity

Plant growth is highly seasonal and closely linked to patterns of rainfall (Figure 11.2). The years 2002/03 and 2004/05 were below average. Vegetation sampling spanned the years 2004-2007, and excluded the relatively high years of 2000/01 and 2001/02. Differences between paddocks were most marked in low rainfall years (2002/03 and 2004/05). In 2005 there was a clear separation of individual paddocks corresponding to the order of utilisation rate.

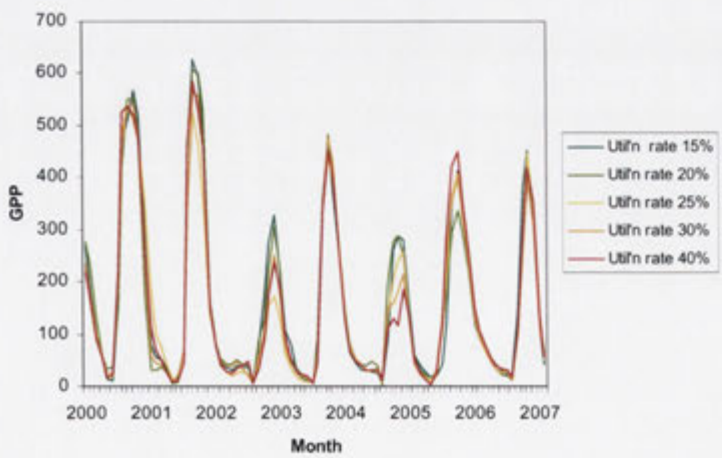
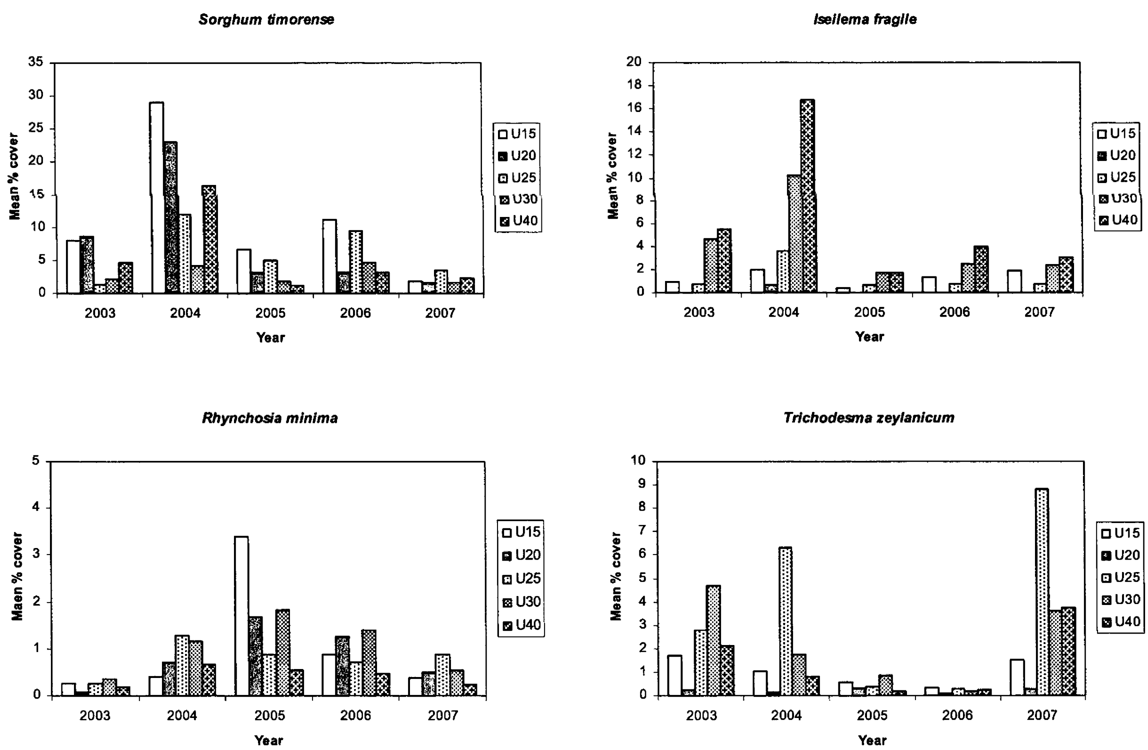


Figure 11.2 Monthly GPP (mmol CO_2m^{-2} day^{-1}) in each of five pasture utilisation rate treatment paddocks.

Data derived from averaged values of 100 random points in each treatment area.

11.3.3 Variation in mean projected foliage cover

At Pigeon Hole Station one hundred and fifty plant taxa were recorded within quadrats during the surveys of pasture utilisation plots between 2003 and 2007. Of these only 26 taxa had mean projected foliage cover values of >0.1%, and five had mean projected foliage cover values >1%. These include the annual grasses *Sorghum timorense* (6.3%), *Iseilema fragile* (2.9%), the perennial grasses *Chrysopogon fallax* (2.2%) and *Aristida latifolia* (1.1%) and the perennial herb *Flemingia pauciflora* (2.8%). Individual taxa varied in mean cover values between sites and years (Figure 11.3). The annual grasses *S. timorense* and *I. fragile* both had high mean cover values in 2004, though patterns of abundance varied between sites. The food plants *Trichodesma zeylanicum* (Boraginaceae) and *Chionachne hubbardiana* both had minimum cover values in 2005 and 2006, while the prostrate perennial leguminous herb *Rhynchosia minima* (Fabaceae) increased in these years. The ephemeral herb *Blumea tenella* (Asteaceae) was not detected in 2005. These results suggest that the responses of individual species to variation in rainfall patterns and grazing are variable and idiosyncratic.



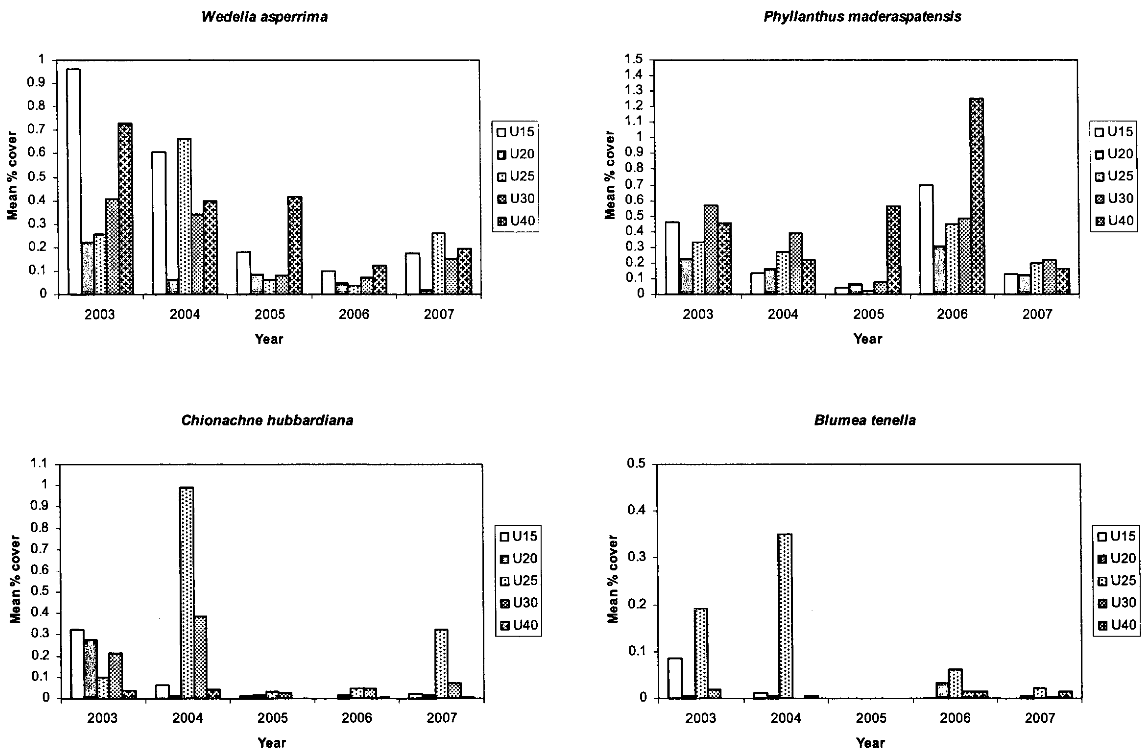


Figure 11.3 Mean projected foliage cover values of eight selected taxa in five levels of pasture utilisation.

Taxa include dominant annual grasses *Sorghum timorense* (Poaceae) and *Iseilema fragile* (Poaceae), food plants *Trichodesma zeylanicum* (Boraginaceae), *Wedelia asperrima* (Asteraceae), *Chionachne hubbardiana* (Poaceae), *Rhynchosia minima* (Fabaceae), *Phyllanthus maderaspatensis* (Euphorbiaceae) and the ephemeral herb *Blumea tenella* (Asteraceae).

11.3.4 Effect of year and grazing treatment on plant abundance: Pigeon Hole study

Binomial modelling of the frequency of occurrence of three food plants using the factors YEAR, UTIL_RATE and SPECIES yielded a weak model with three terms (Table 11.4). The test for over-dispersion (c=4.5) indicated that the data structure was inappropriate for the model and results cannot be interpreted unambiguously. Parameter estimates suggest that the frequency of occurrence of all species was less in years 2005 and 2006, that *C. hubbardiana* was less frequent than other species, and that pasture utilisation has an inconsistent effect (Table 11.5).

Table 11.4 Results of generalised linear modelling of frequency of occurrence of three food plants in grazing treatments from 2003-2007.

Data from Pigeon Hole grazing experiment.

Model	Log likelihood	k	AICc	d.AICc	wi	pcdev
YEAR+SPECIES+UTIL_RATE	-1499.66	12	3023.94	0.00	1.000	23.3
YEAR+SPECIES	-1582.14	8	3180.57	156.63	0.000	17.7
YEAR+UTIL_RATE	-1613.56	10	3247.55	223.61	0.000	15.5
UTIL_RATE+SPECIES	-1649.02	8	3314.32	290.37	0.000	13.1
YEAR	-1694.44	6	3401.04	377.10	0.000	10.0
SPECIES	-1730.66	4	3469.40	445.45	0.000	7.5
UTIL_RATE	-1759.95	6	3532.06	508.12	0.000	5.5
Null model	-1840.29	2	3684.60	660.65	0.000	0.0

Table 11.5 Model parameters of preferred model of variation in frequency of occurrence of three food plants.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-2.282	0.112	-20.37	<0.0001	***
YEAR2004	-0.079	0.088	-0.89	0.3731	ns
YEAR2005	-1.068	0.109	-9.82	<0.0001	***
YEAR2006	-1.300	0.116	-11.18	<0.0001	***
YEAR2007	0.065	0.086	0.76	0.4491	ns
SPECIESTRICH	1.167	0.087	13.39	<0.0001	***
SPECIESWEDEL	1.040	0.088	11.79	<0.0001	***
UTIL_RATE_20	-1.284	0.138	-9.32	<0.0001	***
UTIL_RATE_25	0.197	0.097	2.02	0.0433	*
UTIL_RATE_30	-0.064	0.091	-0.70	0.4835	ns
UTIL_RATE_40	-0.052	0.097	-0.53	0.5942	ns

Binomial modelling of the frequency of occurrence of *C. hubbardiana* yielded a weak model with terms YEAR and UTIL_RATE (Tables 11.6 and 11.7). The frequency of occurrence of this species declined from 2003 and 2004 to rarity in 2005 and 2006, and was consistently high in treatment U25%, and least in treatment U40% (Figure 11.4). The patterns of relative abundance between paddocks are identical to 2003 and a grazing effect cannot be inferred.

Table 11.6 Results of generalised linear modelling of frequency of occurrence of *Chionachne hubbardiana* in grazing treatments from 2003-2007.

Model	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
YEAR+UTIL_RATE	-366.83	10	221.54	0.00	0.923	16.9
YEAR	-392.99	6	226.68	5.14	0.071	9.6
UTIL_RATE	-402.18	6	231.64	10.10	0.006	7.1
Null model	-427.79	2	236.91	15.37	0.000	0.0

Table 11.7 Model parameters of preferred model of variation in frequency of occurrence of *Chionache hubbardiana*.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-1.954	0.201	-9.71	0.0000	***
YEAR2004	-0.300	0.188	-1.59	0.1114	ns
YEAR2005	-1.527	0.267	-5.72	0.0000	***
YEAR2006	-1.704	0.285	-5.98	0.0000	***
YEAR2007	-0.743	0.209	-3.56	0.0004	***
UTIL_RATE_20	-0.740	0.290	-2.56	0.0106	*
UTIL_RATE_5	0.497	0.217	2.29	0.0220	*
UTIL_RATE_30	0.093	0.212	0.44	0.6628	ns
UTIL_RATE_40	-1.146	0.306	-3.75	0.0002	***

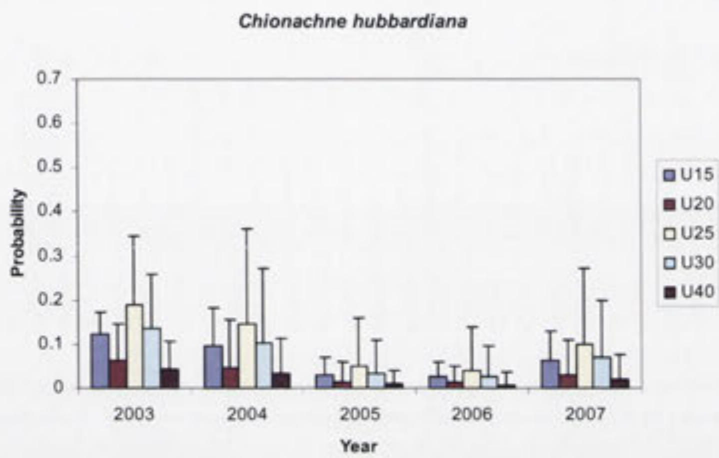


Figure 11.4 Probability of occurrence (± 95% confidence limits) of *Chionachne hubbardiana* in five grazing treatments from 2003-2007.

Binomial modelling of the frequency of occurrence of *T. zeylanicum* yielded a reasonably robust model with terms YEAR and UTIL_RATE (Tables 11.8 and 11.9). Occurrence was least in U20% and consistently high in treatment U25% (Figure 11.5). As above, a grazing effect cannot be unambiguously inferred from this result, simply that the frequency of occurrence of this species differed among paddocks for reasons which may or may not be related to the experimental treatment.

Results indicated that the model data for *W. asperrima* was severely over-dispersed (c = 5.5), and no further results are presented.

Table 11.8 Results of generalised linear modelling of frequency of occurrence of *Trichodesma zeylanicum* in grazing treatments from 2003-2007.

Model	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
YEAR+UTIL_RATE	-487.81	10	261.62	0.00	1.000	33.7
YEAR	-546.81	6	281.43	19.81	0.000	21.5
YEAR*UTIL_RATE	-465.02	26	291.42	29.80	0.000	38.4
UTIL_RATE	-594.88	6	304.88	43.26	0.000	11.6
Null model	-651.24	2	323.83	62.21	0.000	0.0

Table 11.9 Model parameters of preferred model of variation in frequency of occurrence of *Trichodesma zeylanicum*.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-1.493	0.151	-9.88	0.0000	***
YEAR2004	0.019	0.138	0.14	0.8880	ns
YEAR2005	-1.332	0.182	-7.30	0.0000	***
YEAR2006	-1.506	0.192	-7.83	0.0000	***
YEAR2007	0.387	0.133	2.91	0.0036	**
UTIL_RATE_20	-1.089	0.221	-4.94	0.0000	***
UTIL_RATE_25	0.824	0.156	5.29	0.0000	***
UTIL_RATE_30	0.361	0.149	2.43	0.0152	*
UTIL_RATE_40	0.011	0.164	0.07	0.9479	ns

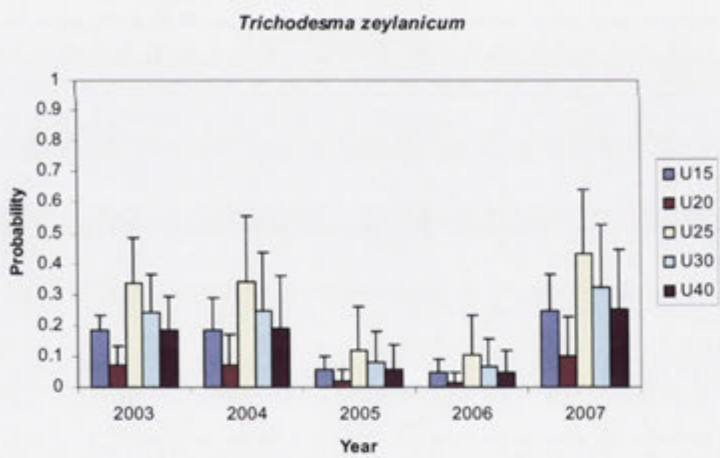


Figure 11.5 Probability of occurrence (± 95% confidence limits) of *Trichodesma zeylanicum* in five grazing treatments from 2003-2007.

11.3.5 Modelling occurrence of food plants in grazed versus ungrazed sites: Pigeon Hole study

MDS ordination of plant community data from exclosures and ambient sites within the paddock with the highest level of grazing pressure (U40%) showed that the relative abundance of the three food plant species differs among sites and sampling occasions, with *C. hubbardiana* tending to have maximum abundances at ungrazed sites, and *T. zeylanicum* and *W. asperrima* tending to have maximum abundances at grazed sites (Figure 11.6).

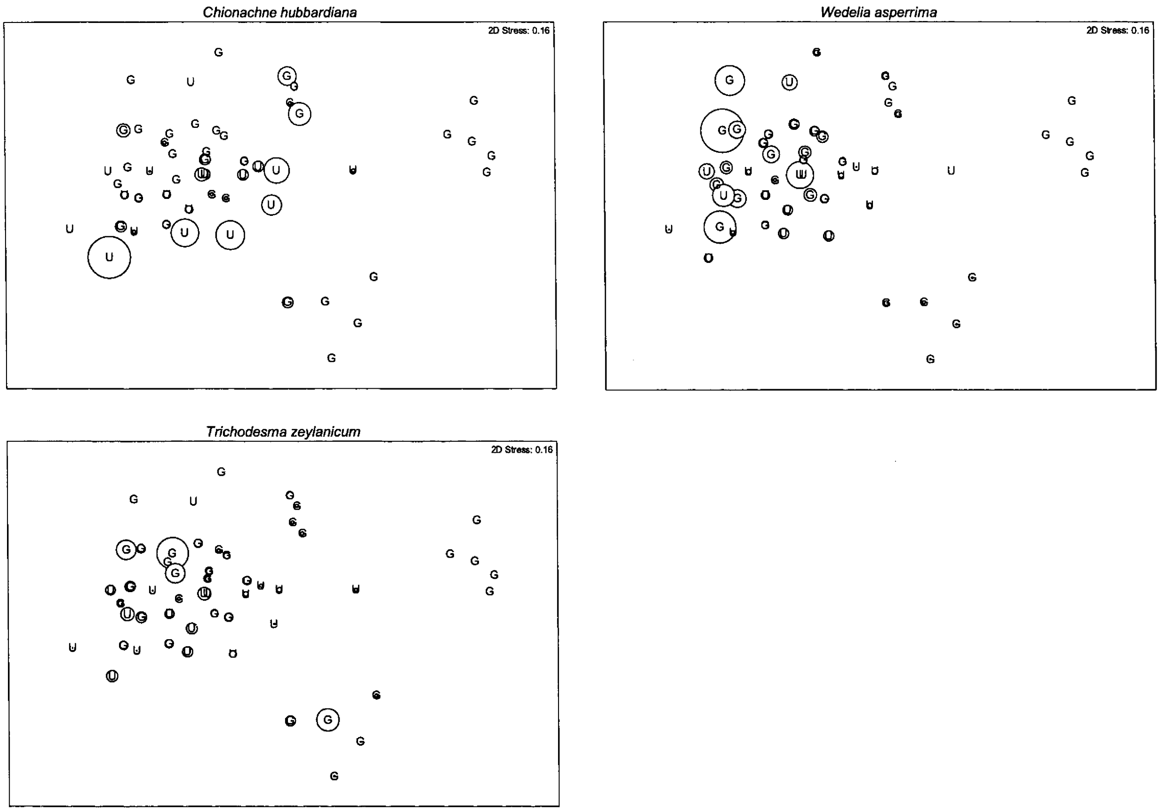


Figure 11.6 Bubble-plots of abundance of three food plants at grazed and ungrazed sites in high utilisation treatment paddock.

G = grazed; U = ungrazed exclosures.

Binomial modelling of the frequency of occurrence of individual species yielded a robust model for *C. hubbardiana* indicating a significant effect of grazing. The preferred model included the single term GRAZE_TYPE, though the next preferred model with YEAR and GRAZE_TYPE was within the interval for acceptable support of candidate models. Modelling suggests inter-annual differences in the frequency of occurrence of this species, and a negative effect of grazing (Tables 11.10 and 11.11, Figure 11.7). The model for *T. zeylanicum* was also robust and included only the term YEAR, with no evidence of an effect of grazing on the frequency of occurrence of this species (Tables 11.12 and 11.13). Model data for *W. asperrima* is severely over-dispersed ($c = 6.2$) and no further results are presented.

Table 11.10 Results of generalised linear modelling of frequency of occurrence of *Chionachne hubbardiana* in grazed and ungrazed sites in high utilisation (40%) treatment paddock.

Model	Log likelihood	k	QAIC	d.QAICc	wi	pcdev
GRAZE_TYPE	-49.39	3	68.44	0.00	0.637	32.9
YEAR+GRAZE_TYPE	-45.48	5	69.57	1.13	0.362	42.2
Null model	-63.23	2	82.37	13.93	0.001	0.0
YEAR	-59.49	4	83.30	14.86	0.000	8.9

Table 11.11 Model parameters of preferred model of frequency of occurrence of *Chionachne hubbardiana.*

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-1.372	0.257	-5.34	0.0000	***
YEAR2006	-1.129	0.433	-2.61	0.0091	**
YEAR2007	-0.602	0.373	-1.61	0.1068	ns
GRAZE_TYPE	-1.766	0.362	-4.88	0.0000	***

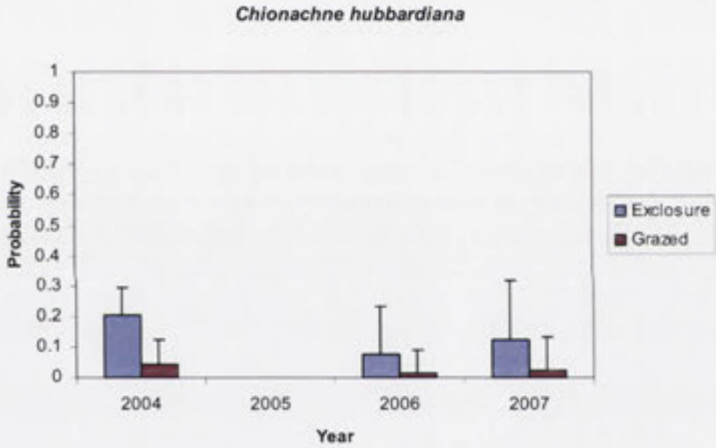


Figure 11.7 Probability of occurrence (± 95% confidence limits) of *Chionachne hubbardiana* in grazed and ungrazed sites in high utilisation treatment paddock.

Table 11.12 Results of generalised linear modelling of frequency of occurrence of *Trichodesma zeylanicum* in grazed and ungrazed sites in high utilisation treatment paddock.

Model	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
YEAR	-76.69	5	90.32	0.00	0.773	59.3
YEAR+GRAZE_TYPE	-76.22	6	92.81	2.50	0.222	59.8
YEAR*GRAZE_TYPE	-73.55	9	100.26	9.94	0.005	62.9
Null model	-128.39	2	133.53	43.21	0.000	0.0
GRAZE_TYPE	-127.98	3	135.60	45.28	0.000	0.5

Table 11.13 Model parameters of preferred model of frequency of occurrence of *Trichodesma zeylanicum*.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-1.072	0.162	-6.61	0.0000	***
YEAR2005	-3.113	0.604	-5.15	0.0000	***
YEAR2006	-1.679	0.339	-4.95	0.0000	***
YEAR2007	0.225	0.224	1.00	0.3150	ns

11.3.6 Effect of year and grazing treatment on plant abundance: Mount Sanford study

At Mount Sanford, binomial modelling of the frequency of occurrence of all three food plant species among years and grazing treatments yielded a robust model with terms YEAR and SPECIES and indicated that the frequency all species differed in 2003 and 2006 relative to 2002, and that the frequency of *T. zeylanicum* and *W. asperrima* differed relative to *C. hubbardiana* (Tables 11.14 and 11.15, Figure 11.8). Models for individual species demonstrated support for inter-annual variation in frequency of occurrence, but no support for effects of grazing treatments for any species (Tables 11.16-11.21). In summary, at Mount Sanford there was no substantial evidence of effects that can be attributed to grazing on the frequency of occurrence of food plants of the Flock Bronzewing Pigeon.

Table 11.14 Results of generalised linear modelling of frequency of occurrence of three food plants in grazing treatments from 2002, 2003 and 2006.

Data from Mount Sanford grazing experiment.

Model	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
YEAR+SPECIES	-545.33	6	349.35	0.00	0.530	55.8
YEAR+SPECIES+UTIL_RATE	-535.07	9	349.58	0.24	0.470	57.1
YEAR	-724.60	4	455.16	105.81	0.000	33.1
YEAR+UTIL_RATE	-715.62	7	456.05	106.71	0.000	34.2
SPECIES	-827.32	4	518.23	168.88	0.000	20.1
UTIL_RATE+SPECIES	-818.78	7	519.39	170.05	0.000	21.2
Null model	-985.81	2	611.36	262.02	0.000	0.0
UTIL_RATE	-977.96	5	612.83	263.48	0.000	1.0

Table 11.15 Model parameters of preferred model of variation in frequency of occurrence of three food plants.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-0.991	0.092	-10.81	0.0000	***
YEAR2003	0.619	0.098	6.34	0.0000	***
YEAR2006	-2.230	0.153	-14.62	0.0000	***
SPECIESTRICH	0.722	0.100	7.23	0.0000	***
SPECIESWEDEL	-1.524	0.138	-11.08	0.0000	***

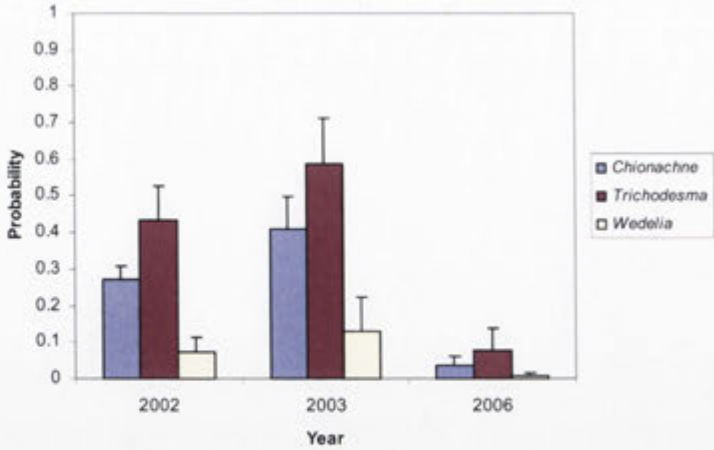


Figure 11.8 Probability of occurrence (± 95% confidence limits) of three food plants from 2002, 2003 and 2006.

Data from Mount Sanford grazing experiment.

Table 11.16 Results of generalised linear modelling of frequency of occurrence of *Chionachne hubbardiana* in grazing treatments from 2002, 2003 and 2006.

Model	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
YEAR	-197.80	4	115.74	0.00	0.911	49.7
YEAR+UTIL_RATE	-192.64	7	120.38	4.64	0.089	51.7
Null model	-326.03	2	179.14	63.40	0.000	0.0
UTIL_RATE	-321.70	5	183.78	68.05	0.000	1.7

Table 11.17 Model parameters of preferred model of variation in frequency of occurrence of *Chionachne hubbardiana*.

Data from Mount Sanford grazing experiment.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-0.837	0.111	-7.54	0.0000	***
YEAR2003	0.447	0.152	2.94	0.0033	**
YEAR2006	-3.240	0.374	-8.68	0.0000	***

Table 11.18 Results of generalised linear modelling of frequency of occurrence of *Trichodesma zeylanicum* in grazing treatments from 2002, 2003 and 2006.

Data from Mount Sanford grazing experiment.

Model	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
YEAR+UTIL_RATE	-180.16	7	140.93	0.00	0.526	67.0
YEAR	-191.31	4	141.15	0.22	0.473	63.1
YEAR*UTIL_RATE	-173.58	13	153.53	12.60	0.001	69.3
Null model	-372.65	2	260.04	119.11	0.000	0.0
UTIL_RATE	-364.343	5	261.33	120.40	0.000	2.9

Table 11.19 Model parameters of preferred model of variation in frequency of occurrence of *Trichodesma zeylanicum*.

Data from Mount Sanford grazing experiment.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	0.256	0.159	1.62	0.1062	ns
YEAR2003	0.616	0.148	4.15	0.0000	***
YEAR2006	-2.747	0.232	-11.87	0.0000	***
UTIL_RATE_23	-0.826	0.199	-4.15	0.0000	***
UTIL_RATE_39	-0.305	0.196	-1.56	0.1191	ns
UTIL_RATE_47	-0.708	0.198	-3.58	0.0003	***

Table 11.20 Results of generalised linear modelling of frequency of occurrence of *Wedelia asperrima* in grazing treatments from 2002, 2003 and 2006.

Data from Mount Sanford grazing experiment.

Model	Log likelihood	k	QAICc	d.QAICc	wi	pcdev
YEAR	-113.66	4	122.08	0.00	0.875	17.4
YEAR+UTIL_RATE	-110.21	7	126.08	4.00	0.118	21.5
Null model	-128.65	2	132.18	10.10	0.006	0.0
UTIL_RATE	-125.28	5	135.83	13.75	0.001	3.9

Table 11.21 Model parameters of preferred model of variation in frequency of occurrence of *Wedelia asperrima*.

Data from Mount Sanford grazing experiment.

Model variable	Estimate	Std Error	z value	Pr(>|z|)	Sig.
Constant	-3.622	0.320	-11.30	0.0000	***
YEAR2003	1.652	0.356	4.64	0.0000	***
YEAR2006	0.762	0.379	2.01	0.0442	*

11.4 DISCUSSION

The assessment of grazing impacts on native vegetation in grassy landscapes is fraught with a number of problems: foremost amongst these is the ubiquity of grazing impacts and the lack of benchmark or reference sites without a history of grazing by domestic herbivores. This is particularly evident in the relatively homogeneous Mitchell grasslands of northern Australia which have an uninterrupted grazing history since the rapid and complete occupation of productive pastoral lands after European settlement. Long-term studies of plant community dynamics of Australian grasslands frequently monitor recovery from a degraded state (e.g. Williams and Mackey 1982, Foran and Bastin 1984), and invariably there will be problems in attributing the intensity and impacts of past grazing.

This study provided evidence of very substantial inter-annual variation in the abundance of food plant species, that was consistent between different measurement methods and scales. However, the effects of grazing on abundance of food plants were less conclusive. Both *Wedelia asperrima* and *Trichodesma zeylanicum* are prevalent in grazed landscapes and may both increase in abundance under at least moderate grazing pressure. There is convincing evidence from this study that *Chionachne hubbardiana* is sensitive to grazing. The data suggest an underlying grazing impact that may readily be swamped or obscured by variation between years and by spatial effects. There is no convincing evidence that favours a given utilisation rate or grazing system. Results from other studies within the Pigeon Hole project suggest that rotational wet season spelling, with spelling for the duration of the wet season, minimises loss of perennial grass basal area (White 2007). Rotational wet season spelling guarantees seed replenishment in at least part of the pastoral landscape and has intuitive appeal as a land management strategy to allow persistence of granivorous birds in these landscapes. Further information is needed on the links between management practices and faunal responses.

There were several design constraints in this study which confounded interpretation of analyses. There was a single year of data collection prior to imposition of grazing trials: during this period treatments were continuously grazed but there are no data on relative condition of different treatment units. Data on gross primary productivity from satellite-borne sensors suggests that the prior condition of treatment areas was not uniform and that intensity of recent grazing differed between treatments. The grazing trial spanned four years to capture inter-annual variation in rainfall pattern. The need to consider inter-annual variation in ecological phenomena in northern Australia has been repeatedly stressed. Long-term studies are required to capture the full suite of occasionally subtle variation in patterns of rainfall which may have significant ecological implications. Based on an analysis of the patterns of recurrence of rainfall patterns in coastal Darwin in the Northern Territory, Taylor and Tulloch (1985) suggest that ecological studies should continue for at least six to eight years. Jones *et al.* (1995) suggested a minimum of ten years for monitoring experimental sites, whilst Phelps *et al.* (1993) suggested ongoing monitoring to capture 10-15 major climatic events. Such requirements are barely met in studies in the northern rangelands. Prior to the commencement of the grazing trial there was a significant rainfall event in 2000/01: large infrequent events such as this are likely to be of considerable ecological significance and may leave a trace that endures for several subsequent years (Gutierrez *et al.* 2000, Holmgren *et al.* 2006).

The scale of measurement of biodiversity indicators, including plant abundance and occurrence, generally yielded weak tests of the effects of experimental treatments on biota. The design is overwhelmed by spatial differences within experimental treatments and frequent over-dispersed data. Over-dispersion arises when the sampling variance exceeds the theoretical model-based variance which may result in biased estimates of model parameters (Burnham and Anderson 2002).

Assessment of grazing impacts must confront the analytical conundrum that data for rare species may be insufficient for rigorous analysis, and analyses are confined to taxa which are largely resilient to grazing (Fisher 2001). Further, it is possible that species have been extirpated from entire landscapes by a long history of grazing. For example, the annual grass *Echinochloa turneriana* is now rare in open grazed landscapes on the Barkly Tableland but is abundant in grazing refuges such as Connell's Lagoon Conservation Reserve (Johnson *et al.* 1982). Anecdotal evidence suggests that the large seeds of *E. turneriana* provided an important resource for granivorous birds. Similarly, the annual grass *Oryza australiensis* has declined in grazed landscapes in northern Australia (Jaensch 2006). Both species produce large seeds, have an erect growth form, and are confined to the wetter parts of the landscape. Examples of links between population declines of birds and declines in the availability of resources from specific plants include the Long-billed Corella *Cacatua tenuirostris* and the tuberous daisy *Microseris lanceolata* (Emison *et al.* 1994), and the Golden-shouldered Parrot *Psephotus chrysopterygius* and the perennial grass *Alloteropsis semialata* (Crowley and Garnett 2001, Crowley 2008).

The pre-pastoral patterns of resource abundance for granivorous birds in northern grasslands may be largely irretrievable. Fire has largely been eliminated as an ecological agent from perennial grasslands (Wilson 1990); consequently, birds which may have exploited post-fire seed pulses, or which used resources from plants common in the early seral stages of succession, may be disadvantaged. The ecological effects of fire in Mitchell grasslands remain poorly described aside from studies on seeding responses of the tussock-grass *Astrebla* (Scanlan 1980), and emergence and survival of seedlings of the annual grass *Iseilema* spp. (Scanlan and O'Rourke 1982).

Broadly this study suggests that pastoral management, at pasture utilisation levels of 15-40%, has relatively little impact on plants and seed resources used by Flock Bronzewing Pigeons, and indeed that some favoured plant species are resilient to, or may be favoured by, more intensive grazing. But, such conclusions should be tempered by the subtlety of the requirement of Flock Bronzewing Pigeons for continual resources and that impacts may occur on plant species critical at particular times of the year, and that potentially critical crunches may occur in 'poor' years (when cattle impacts may be most severe). During the early wet season Flock Bronzewing Pigeons appeared to favour wetter parts of the landscape which were floristically distinct from dry season habitat (Chapters 8 and 10). It may be that the nature of impacts differs between seasons, and that the effects of long-term moderate grazing on resource abundance in the dry season are benign, and that deleterious effects are confined to specific critical habitats and plant species at other times. Limited evidence from field data suggests that the plant *Commelina tricarinata* and the fringes of inundated depressions might be a suitable target for further investigation.

11.5 SUMMARY OF FINDINGS AND CONCLUSIONS

Data on plant species richness and abundance from two large-scale grazing experiments in relevant habitats were analysed to test the effects of grazing on the abundance and frequency of occurrence of three key food plants of the Flock Bronzewing Pigeon. Grazing experiments were conducted over five years (2003-2007) on Pigeon Hole Station in the Victoria River District, and over a similar period (2002-2006) on Mount Sanford Research Station, also in the Victoria River District. The primary manipulation was imposition of constant pasture utilisation rates, with five levels in the Pigeon Hole experiment, and four levels in the Mount Sanford experiment, by adjustment of stocking rates to deplete fixed proportions of standing forage in the following twelve months.

Analyses focussed on four plant species known to contribute substantial amounts of seed to the food of Flock Bronzewing Pigeons in similar habitat elsewhere in the Northern Territory. Data on three species was sufficient for analysis including the annual grass *Chionachne hubbardiana*, and the ephemeral forbs *Trichodesma zeylanicum* and *Wedelia asperrima*, whilst the fourth, the annual forb *Phyllanthus lacerosus*, was not recorded by these studies and may not have been differentiated from the abundant and widespread *P. maderaspatensis*.

Preliminary analyses suggested that all three species are common and persist in grazed landscapes, though their relative abundance differed between study areas. Ordination modelling of plant community data from Pigeon Hole suggests that these species do not show marked habitat differentiation and co-occur with the perennial tussock-grass *Astrebla elymoides*.

Binomial modelling of the frequency of occurrence of these species revealed effects associated with grazing utilisation levels in one study, and none in the second study. Grazing effects cannot be unambiguously inferred from these results and may relate to pre-existing edaphic site differences or differential grazing history. There is substantial evidence of inter-annual variation in frequency of occurrence of all three species.

Analysis of patterns of frequency of occurrence within exclosures and ambient sites in a severely grazed paddock identified a negative effect of grazing for *C. hubbardiana*, but provided no evidence of a grazing effect for the remaining species. Both *T. zeylanicum* and *W. asperrima* persist in grazed landscapes, and may be favoured by sustained high grazing pressure. Conversely, *C. hubbardiana* may be less resilient to sustained grazing pressure. Other species which provided resources for granivorous birds prior to pastoral occupation may have been extirpated from these landscapes.

Chapter 12: SYNTHESIS AND CONCLUSIONS

12.1 INTRODUCTION

The studies presented in this thesis represent substantial progress in understanding of several critical aspects of the ecology, and consequently the conservation management requirements, of the Flock Bronzewing Pigeon. The major findings and shortcomings of this research are reviewed in the section below and summarised in Table 12.1. Subsequent sections present a synthesis of these results, and a discussion of the potential management implications. The chapter ends with a summary of recommendations for further research on this species.

12.2 SUMMARY OF MAJOR FINDINGS OF THIS STUDY

Data records of Flock Bronzewing Pigeons were compiled from various sources to summarise distribution patterns and conduct distributional modelling. Flock Bronzewing Pigeons remain widespread and periodically common throughout large areas of their former range including Mitchell grasslands of the Barkly Tableland and floodplains of Channel Country drainages, especially parts of the Georgina river system. The majority of records (~80% of >1,200 records) occurred within either the Northern Territory or Queensland; a large proportion (~40%) occurred within the Mitchell Grass Downs bioregion. Of 195 cells of one degree latitude and longitude, 90 (46%) have records from 5 or more separate years; these are clustered in the Barkly Tableland in the Northern Territory and the Channel Country of far south-west Queensland, though outliers occur in the Victoria River and Tanami regions of the Northern Territory. Modelling of presence and 'pseudo-absence' data generated distributional models which explained up to 54.6% of the model deviance. Model results are consistent with previous descriptions of typical Flock Bronzewing Pigeon habitat. The shortcomings of this modelling approach include the appropriateness of the scale of modelling (i.e. cell size of 0.1 decimal degrees), and the assumptions associated with modelled presence and absence values. Presence values, if averaged over repeat visits, may be less than 1, while absence values are in fact unknown and may be greater than 0.

The spatial distribution of Flock Bronzewing Pigeon records was examined with seven five-year intervals from 1971-2005. Whilst data are sparse for some periods, there is a general trend for relatively large numbers of records in the Lake Eyre Basin in periods following high rainfall, and for relatively few records in sustained low rainfall periods; and to be continuously present in the Barkly region even in low rainfall periods. The distribution of records within individual years in relation to seasonal rainfall patterns was examined for years with sufficient records. Whilst there are indications that the spatial distribution of Flock Bronzewing Pigeons is correlated with rainfall in some years, the reverse was frequently also true. Records of large aggregations of Flock Bronzewing Pigeons are frequently associated with years of above average seasonal rainfall preceded by drought years.

A mail-out survey of rangeland users was used to document the patterns of occurrence of Flock Bronzewing Pigeons throughout their range. Survey forms were returned from 406 rangeland residents; the majority from central Queensland, reflecting the bias in the density of settlement and human population within the rangelands. More than a third of respondents (36%) indicated that Flock Bronzewing Pigeons had occurred on their property; with 71.2% of these indicating that Flock Bronzewing Pigeons had been observed in the previous 12 months. Respondents perceived at least four episodes of high Flock Bronzewing Pigeon abundance since the 1950s; these corresponded with periods of widespread above average rainfall. Modelling of the patterns of occurrence in relation to type of pastoral land use did not yield a supportable model, though the test was relatively weak.

The response to this mail-out survey and subsequent intensive surveys indicated that pastoral zone residents are knowledgeable and potentially willing participants in long-term ecological research and monitoring in the rangelands. Careful planning is required to ensure longevity and data value for any future monitoring program. Community-based surveys inevitably contend with issues of data quality which may compromise data analysis and interpretation. There are, however, considerable benefits which outweigh these considerations, including spatial coverage, the potential for a long-term temporal perspective, and the opportunity that engagement may encourage landholders to consider and development conservation management actions. The principal shortcoming of this survey was the bias in the distribution of respondents; regions such as the Channel Country and Barkly Tableland are occupied by relatively few, large pastoral enterprises and consequently the density of potential respondents is low. The principal findings were not compromised by this bias.

Rangeland residents within the range of the Flock Bronzewing Pigeon were surveyed on a monthly basis to provide information on the relative abundance of Flock Bronzewing Pigeons on their property. The survey yielded more than 1,200 responses from 118 observers within 62 one-degree cells. Patterns of abundance varied between regions in response to differences in patterns of rainfall and plant productivity. The movement strategy appears to be serial invasion of resource rich patches, which may be generated by significant rainfall events after a period of drought. Nesting is frequently associated with invasion episodes; aggregations are dispersed by rainfall usually in early summer months. This contradicts the assertion that large numbers follow sustained periods of favourable conditions (Higgins and Davies 1996). Population responses can be rapid given favourable conditions, and favourable conditions are generally not sustained from year to year. Much further work is required over a prolonged period to elucidate the timing, nature and extent of movement responses in relation to environmental cues. An understanding of the interactions between movement behaviours and habitat attributes will underpin conservation management of this species. The principal shortcoming of this study is the lack of complementary evidence from satellite tracking of individual birds; much further work is required to guarantee success with routine deployment of these devices in this species.

Results of dietary studies at a site in the Barkly Tableland are consistent with, but substantially extend, the limited earlier published data (Frith *et al.* 1976). Flock Bronzewing Pigeons are primarily granivorous, and there was no evidence of significant amounts of invertebrate or plant leaf material in the food at any time. From 17 samples collected over the period June 2006 to September 2007, the food included seeds of 35 species from 15 plant families, but was dominated by seed of only four annual plant species (*Trichodesma zeylanicum*, *Wedelia asperrima*, *Phyllanthus lacerosus* and *Chionachne hubbardiana*), which in total comprised over 90% of the total number of seeds and the dry weight of food. The relative contribution of each differed between samples, with *T. zeylanicum* dominant in late dry and wet season samples, and with *C. hubbardiana* dominant in dry season samples in 2007. Seed of *W. asperrima* was important in the June 2006 sample, but not thereafter. Knowledge of the food requirements elsewhere within their range remains sparse. Biogeographic analysis of plant communities of Mitchell grasslands has not been undertaken at a bioregional scale, though evidence from the Northern Territory (Fisher 2001) and Queensland (Fensham *et al.* 2000) suggest similarities in floristic composition and that the spectrum of resources available to granivorous birds may be similar. This is supported by anecdotal information from the Gulf Plains region (Jaensch pers. comm.), where Flock Bronzewing Pigeons were observed feeding in company with Galahs *Eolophus roseicapillus* in burnt grassland containing the annual grass *C. hubbardiana*. Conversely the spectrum of seed resources in the Channel Country is likely to differ substantially. Available evidence suggests that seed of annual verbine *Cullen cinereum* is the principal food in this region. The four principal species present in the food at Helen Springs occur in black-soil habitats across northern Australia, though are not confined to Mitchell grasslands. At least two of these preferred species are not favoured by grazing stock (*W. asperrima* and *T. zeylanicum*), and may have weedy characteristics.

Wet season food requirements of Flock Bronzewing Pigeons are not well described and remain an area of critical need for further work. Limited dietary information, supported by observational and satellite-tracking data, suggests a shift to run-on areas including bluebush swamps. Bluebush swamps have a highly fragmented distribution within the broad Mitchell grasslands landscape, possess distinctive floristic composition and high conservation value (Brock 2000), and are occasionally subject to high grazing pressure (Perry and Christian 1954) which has led to widespread degradation. These observations lead to the working hypothesis that birds seek seed of early seeding perennial plants in these habitats (such as *Commelina tricarinata*), and that degradation of these habitats by stock may result in discontinuity in food resources. This hypothesis can easily be addressed by additional data on wet season foraging site selection and stock exclosure experiments. The plant *C. tricarinata* is poorly known and is listed as Data Deficient under the Territory Parks and Wildlife Conservation Act.

The attributes of 22 sites used by Flock Bronzewing Pigeons in dry season months were compared with those of 63 randomly selected grassland sites at my main study site of Helen Springs Station on the Barkly Tableland. Bird use of sites was inferred by direct observation or by detection of signs including feathers and faecal pellets. Ordination of plant community composition data of used and unused sites suggested that used sites clustered in a portion of the ordination space shared by the perennial tussock-grass *Astrebla elymoides* and food plants *Chionachne hubbardiana*, *Wedelia asperrima* and *Trichodesma zeylanicum*. Non-parametric *t*-tests suggested that bird use of sites was strongly associated with the dry weight of seed of food plants present at a site. Binomial modelling of the probability of occurrence of Flock Bronzewing Pigeons yielded a model which included percentage cover of *C. hubbardiana* and *W. asperrima*. These results describe habitat preferences of Flock Bronzewing Pigeons during dry season months; further work is required to adequately document habitat use during wet season months. Data from satellite telemetry, described below, provides some insights on habitat use during this critical phase of the annual cycle.

Surveys of 35 20 x 20 m plots in Mitchell grassland habitats in 2006 and 2007 at my main study site of Helen Springs Station on the Barkly Tableland revealed substantial inter-annual variation in plant community structure consistent with variation in seasonal rainfall. One hundred and twenty one plant taxa were recorded in the two sampling periods; 114 taxa in 2006 and 102 taxa in 2007. Plant species richness per plot differed significantly between years: mean number per site was 26.5 in 2006 and 22.1 in 2007. Taxa which demonstrated a decline in frequency of occurrence are predominantly annual forbs from several families, those demonstrating an increase in frequency of occurrence are predominantly perennial grasses or perennial forbs particularly in the family Fabaceae. The frequency of occurrence of known food plants differed between years. Multivariate analysis revealed significant difference in compositional structure between years: species contributing to the average dissimilarity between years included the food plants *Wedelia asperrima* and *Trichodesma zeylanicum*.

The abundance of seed of four key food plants of Flock Bronzewing Pigeons varied over time and between floristic groups. Combined seed dry weight on 35 20 x 20 m plots ranged from 0-9.7 g/m^2 in September 2006 to 0-2.7 g/m^2 in September 2007. Count data on seeds was analysed using zero-inflated regression modelling, which yielded models with time by floristic group interactions in each species. Seed numbers consistently declined from late 2006 to late 2007, though patterns differed between species and floristic groups. Maximum seed densities per plot were measured in September 2006 for each species: *Wedelia asperrima* 1,670 seeds/m^2; *Trichodesma zeylanicum* 454 seeds/m^2; *Chionachne hubbardiana* 371 seeds/m^2 and *Phyllanthus lacerosus* 256 seeds/m^2.

A male Flock Bronzewing Pigeon carried a 9.5 g solar-powered satellite transmitter from 27th August 2006 to 19th March 2007. The bird remained within a 10 km radius of the tagging point for approximately four months prior to a substantial rainfall event in mid-January 2007 which triggered a movement response in two stages with a net displacement of 230 km. Subsequently, the bird remained within an area mapped as bluebush *Chenopodium auricomum* swamp on Alroy Downs Station for approximately five weeks. These are the first data on wet season habitat use in this species. Movement coincided with substantial rainfall and a period of lower maximum daily air temperatures. Abundance data collected on Alexandria Station (Appendix 2) suggests a mass exodus during wet season months, a result consistent with data from the tagged individual. The nature and extent of movement of pigeons from Alexandria is unknown. Satellite telemetry holds enormous promise as a technique to reveal the patterns of movement and habitat use by nomadic species in the rangelands. Further work is required to minimise the effects of capture stress in this species and to maximise the probability of survival of tagged individuals.

Data on plant community composition from two pre-existing large-scale grazing experiments in relevant habitats were analysed to test the effects of grazing on the abundance of food plants of the Flock Bronzewing Pigeon. Effects of grazing were confounded by pre-existing spatial differences and consequently analyses lacked inferential power. Analyses of different measures of abundance including frequency of occurrence, mean cover and yield consistently identified inter-annual variation in the food plants *Wedelia asperrima* and *Trichodesma zeylanicum*. These species are not favoured by stock and have probably increased in abundance as a result of grazing; whereas the palatable annual grass *Chionachne hubbardiana* may decrease under grazing.

The study design precluded unambiguous interpretation of the effects of grazing. There are few opportunities to reveal the extent of change from pre-pastoral conditions; there are few parts of the grassland landscape lacking a long history of grazing, and current conservation reserves were frequently subjected to high grazing pressure. Early land system surveys of the Barkly region provide only qualitative descriptions of major plant communities (Perry and Christian 1954). It may be that dietary patterns of the Flock Bronzewing Pigeon have shifted as a result of changes in floristic composition, and that significant providers of seed have been extirpated from much of the landscape, e.g. feasibly including the annual grass *Echinochloa turneriana* (Johnson *et al.* 1982). A far more subtle test of the question would require identification of favoured feeding sites, fencing to exclude cattle, and measurement of plant survival and seed production in fenced and unfenced areas, with experimental duration extending over at least a decade.

Table 12.1 Summary of major findings by chapter.

Chapter title and research questions	Major findings
Chapter 3 Broad-scale distributional modelling	
• What are the broad-scale habitat associations of this species?	• ~40% records in Mitchell Grass Downs bioregion
• Can statistical models be used to identify habitat correlates and predict spatial distribution?	• Spatial modelling identifies key variables including soil texture, rainfall, temperature, elevation and longitude
• Can evidence from database records define the "core" range of this species?	• Highest frequency of annual occurrence in Barkly Tableland, NT, and Channel Country, Qld.
• What is the evidence for range contraction in this species?	• Evidence of range contraction from south-eastern and western periphery
Chapter 4 Spatial and temporal variation in distribution records of the Flock Bronzewing Pigeon	
• Is there evidence that the distribution of Flock Bronzewing Pigeons is determined by rainfall patterns?	• Distribution patterns are variable within five-year intervals, consistent with timing of major flood events
• What are the attributes of rainfall patterns prior to observations of large aggregations of Flock Bronzewing Pigeons?	• Aggregations frequently associated with years of above average seasonal rainfall preceded by drought years
Chapter 5 A community-based survey of the distribution and abundance of the Flock Bronzewing Pigeon	
• What are the intra- and inter-annual patterns of abundance of the Flock Bronzewing Pigeon?	• Weak evidence of seasonal latitudinal movements • Evidence of four episodes of high abundance since mid 1950s
• What are the environmental correlates of patterns of abundance of Flock Bronzewing Pigeons?	• High abundance associated with widespread above-average rainfall • No effect of type of pastoral land use
Chapter 6 Patterns of distribution and abundance of Flock Bronzewing Pigeons: results from a repeated community-based survey	
• Is there evidence that the northern Mitchell grass plains constitute 'core' habitat for this species?	• Three metrics suggest that three areas i.e. Barkly, northern Mitchell grasslands and Channel Country are significant habitat for this species
• Is there evidence of seasonally-based movement patterns for this species?	• No strong evidence of seasonally-based movement patterns
• Are there spatial patterns in relative abundance?	• Temporal patterns of frequency of abundance ranks varied between regions
• If so, what are the correlates of spatial patterns?	• Associated with significant rainfall events, possible link with post-drought rainfall
• Is it possible to infer movement patterns?	• Evidence of reconfiguration of population distribution, but no details of timing and extent of movements
• Is there evidence that supports or refutes either the 'core habitat' or 'serial nomad' model of movement?	• Evidence for 'serial nomad' model with long-term pulsing from core habitat in Barkly, though role of Channel Country probably significant.
Chapter 7 Food of the Flock Bronzewing Pigeon	
• How do dietary patterns vary seasonally and between years?	• In Barkly, seed of four plants comprise 90% of total number seeds and total dry weight of food, but importance varies between samples
Chapter 8 Relationships between floristics and use of sites by Flock Bronzewing Pigeons	
• What attributes are associated with grassland sites used by Flock Bronzewing Pigeons?	• Prefer sites with characteristic species including *Astrebla elymoides* and *Chionachne hubbardiana*
Chapter 9 Patterns of resource availability: from satellites to seeds	
• How does the community structure of Mitchell grasslands vary between years?	• Change in frequency of annual forbs between years
• Does the abundance of seeds of major food species of the Flock Bronzewing Pigeon vary over time and between floristic groups?	• Consistent differences between years corresponding to differences in floristic composition
• Are there differences between species in the	• Temporal patterns consistent for two species, variable

percentage of whole seeds in the seed bank?	for remainder
• What are the implications for Flock Bronzewing Pigeons?	• Decline in resource abundance between years, predict increase in foraging time, decline in individual condition and emigration from area
Chapter 10 Movements of Flock Bronzewing Pigeons: results from satellite telemetry	
• What are the short-term movement patterns of this species, and how do they relate to rainfall and plant productivity?	• Some evidence of long distance dispersal following rainfall in mid January, favour bluebush habitats in wet season months
Chapter 11 Patterns of abundance of food plants of the Flock Bronzewing Pigeon: effects of grazing and inter-annual variation	
• Is there evidence that grazing influences the abundance of known food plants of Flock Bronzewing Pigeons?	• Limited evidence that *Wedelia asperrima* and *Trichodesma zeylanicum* increase under grazing; and converse for *Chionachne hubbardiana*

12.3 TOWARDS A MODEL OF THE DYNAMICS OF FLOCK BRONZEWING PIGEONS

Flock Bronzewing Pigeons are one of several supposedly irruptive taxa in inland Australia. These include raptors Letter-winged Kites *Elanus scriptus*, Grass Owls *Tyto capensis*; waterbirds Black-tailed Native Hens *Gallinula ventralis*, Australian Pelicans *Pelecanus conspicillatus*; and the rodent Long-haired Rat *Rattus villosissimus.* All respond to ecosystem pulses following widespread rainfall and flooding of inland river systems. These species exhibit a variety of movement patterns.

Australian Pelicans episodically migrate from coastal refuges to form large breeding colonies on protected sites within the flooded Lake Eyre system (Reid 2009), and undertake a mass exodus as resources decline. Black-tailed Native Hens occasionally irrupt including to temporary marginal habitats in southern Australia, and return soon after rainfall in inland areas (Matheson 1974, 1978). Raptors respond to rainfall-driven pulses in rodent numbers. Grass Owls expand from core habitat in coastal grasslands to irruptive range throughout large areas of inland Australia (Olsen and Doran 2002). Irruptions of Letter-winged Kites occur in the wake of collapse of prey populations in the Channel Country of central and western Queensland (Hollands 1979). For Australian Pelicans movements are to exploit episodic opportunities for mass breeding and involve concentration and a post-breeding retreat to refuge habitats; for Letter-winged Kites dispersing individuals are probably drought refugees which do not undertake a return journey. Movements of Flock Bronzewing Pigeons do not closely parallel any of these species.

Flock Bronzewing Pigeons remain geographically widespread but centred on an axis from the western Barkly Tableland in the Northern Territory to the north-west corner of New South Wales, and including the entire catchment of the Georgina River (Figure 3.8). These areas may be viewed as parts of a single large system. There is an overall hydrological connection within much of the area: whilst most of the drainage systems of the Barkly are internal and terminate in wetland sumps or lake systems, the south-east Barkly lies in the upper part of the Georgina catchment. Resource pulses in the Channel Country are mostly driven by floods. Local rainfall does not usually initiate a major vegetation response on deeply cracked black soil: an exception occurred in early 2007 after exceptional local rainfall led to substantial flooding in the Eyre Creek system. In some years there will be a resource pulse in Mitchell grasslands of the Barkly region after significant rainfall events, and also a lagged resource pulse in the lower Georgina system as seed is produced by plants which colonise inundated areas during the drying phase.

12.3.1 Are core areas permanently occupied?

Evidence presented in this thesis suggests that Flock Bronzewing Pigeons are probably present year-round in quality sites of the Barkly Tableland. For example, pigeons were present in small numbers on Alexandria Station and elsewhere throughout 2005 after a sequence of below average wet seasons and low seed yield. Their status in the Channel Country is more equivocal. Large numbers of pigeons were present in each year on Glengyle Station after major flooding in the Eyre Creek system in 2001, but were largely absent in 2006 after failure of 2005/06 summer rainfall. I hypothesise that the temporal patterns of seed resources differs between these regions. Whilst the amount and duration of monsoonal rainfall in the Barkly region may be variable, it is predictably reliable and produces an annual seed crop which may vary depending on the amount and timing of rainfall within and between wet seasons. This annual crop is sufficient to maintain small resident populations of pigeons. Conversely, resource pulses in the lower Georgina are associated with episodic flooding events which recur on a multi-annual basis and which produce a seed crop which is depleted gradually over time rather than on a regular annual basis. Large floods may generate a vegetation response and seeding pulse sufficient to maintain large pigeon populations for several years.

12.3.2 What do we know about movements in this species?

Questions on the nature and extent of large-scale movements of Flock Bronzewing Pigeons remain largely unresolved. Resource tracking over large spatial scales was inferred from observations over an eighteen month period in this thesis. Results suggest large-scale reconfiguration of the pattern of dispersion of individuals, but there are alternative models such as aggregation of local, low density populations. A capacity to re-occupy habitat from which they had been absent for several decades was demonstrated within the study period by an invasion to Mitchell grasslands on the Warrego floodplain near Cunnamulla in southern Queensland in early 2008, a phenomenon last observed in the mid-1950s. This observation raises questions such as: What was the source of these arrivals? What factors trigger departure? How do they navigate to locate remote resource rich patches? Long-term data on movement tracks of tagged individuals are needed to elucidate these questions. How pigeons locate resource rich patches within the vast expanses of semi-arid grasslands is a fascinating research question. The navigational ability of domestic pigeons over large distances has been demonstrated repeatedly, and pigeons as a group have a capacity for long-range dispersal and occupation of remote and ephemeral habitats. The hypothesis that pigeons use olfactory cues for navigation has experimental support (Wallraff 2004) and intuitive appeal. Soils emit nitrous gases after wetting, with the amount of emissions varying with soil type and time since previous rainfall (Davidson 1992). It may be that trace gas emissions from long-dry clay soils after heavy rainfall provide navigational clues for granivorous birds to locate resource patches, though there is currently no support for this hypothesis. There is evidence that pelagic oceanic seabirds use olfactory cues to locate dispersed and localised patches of food (Nevitt 2000).

There is evidence from a tagged individual that movements are initiated by significant rainfall events. The data, though limited, suggests a seasonal habitat shift from Mitchell grassland to the fringes of *Chenopodium* swamps. The nature and extent of movements is probably closely linked to patterns of resource availability. Where year-round resource needs are met movements are likely to be contained within core habitat, though within substantial areas of core habitat. The types of resources required by Flock Bronzewing Pigeons vary substantially within their geographic range. Three of the four key food plants identified in dietary studies are widely distributed across northern Australia, but largely confined to northern Mitchell grasslands, and absent from Mitchell grasslands of central and southern Queensland. Knowledge of seed resources used elsewhere within their range is fragmentary or non-existent, though sparse data from Glengyle Station in the Channel Country suggests that seed of Annual Verbine *Cullen cinereum* is important there. The amount and seasonality of rainfall varies along a latitudinal gradient from northern to southern Mitchell grass areas of Queensland, consequently the composition of the interstitial flora is likely to be more variable and less predictable in the southern portion. The composition of the interstitial flora and the types of available seed resources in the central and southern Mitchell grass areas of Queensland may account for the largely transient patterns of occupancy by Flock Bronzewing Pigeons. I propose that there are differences in the composition and dynamics of seed resources available to pigeons between the northern and southern Mitchell grass areas which determine patterns of habitat use. This distinction is largely based on the presence or absence of known key food plants, and especially the annual grass *Chionachne hubbardiana*. Food plants on the southern portion of their range are expected to be small–seeded annual herbs, as yet unidentified. Anecdotal information suggests that seed of ephemeral species such as Tick Weed *Cleome viscosa* may be important. Further data are required on geographic variation in dietary habits of this species.

A genetic basis for behavioural traits associated with migration has been demonstrated for some birds (Berthold 1991). The genetic base for a tendency to migrate (or undertake dispersive movements) may be variable between individuals. Partial migration appears to be particularly prevalent in Australian birds (Chan 2001). Partial migrant populations include individuals that do, and some that do not, migrate from the same breeding area. Nomadic birds must constantly balance the risks of continued occupation of a site versus departure: there may be selective advantages in genotypic variation in movement responses. The existence of heterogeneity in movement responses of Flock Bronzewing Pigeons is unknown, and would require a major program of research.

I speculate that the movements of Flock Bronzewing Pigeons may be classified into three types. Firstly, movements undertaken as part of the daily cycle of activity including commuting between nesting, drinking and foraging sites. Secondly, movements to track resources as they become available in different parts of the landscape on a seasonal basis. Thirdly, opportunistic movement to exploit seeding pulses beyond core habitat. These invasions are frequently associated with synchronous nesting soon after arrival, and may be short-lived (e.g. MacGillivray 1932, McAllan 1996). A conceptual model of Flock Bronzewing Pigeon movements is presented in Figure 12.1.

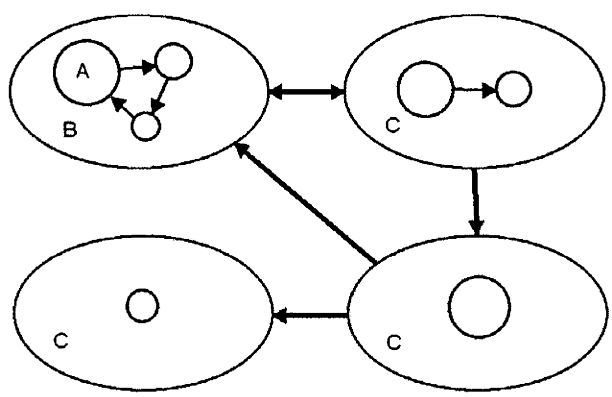


Figure 12.1 Conceptual model of Flock Bronzewing Pigeon movements.

A: represents foraging habitat types within core area of grassland habitat. Circle size indexes relative availability of habitat type. B: Core area of grassland habitat. Movements are mostly contained within core area provided that year-round resource needs are met. C: Occasionally resource needs are not met and birds disperse beyond core area to occupy marginal habitats, which may or may not involve return movement to core area.

The movements undertaken by an individual bird within its lifetime may be complex and defy simple categorisation. An individual bird may be resident within a large 'home-range' for much of year; undertake seasonal directed 'migration' movements between habitat patches;

followed by nomadic occupation of marginal habitats beyond the core range. Roshier (2009) found that the movements of the nomadic Grey Teal *Anas gracilis* indicate prior knowledge of the distribution of resources. Long-lived and social birds such as Flock Bronzewing Pigeons almost certainly perceive the environment at similarly large spatial scales. I contend that the term 'ultra-nomad' may be a mis-nomer. The term nomad implies random, undirected movements. Movements of Flock Bronzewing Pigeons are probably neither random nor undirected.

12.4 CONSERVATION MANAGEMENT IMPLICATIONS

12.4.1 What are the priority areas for conservation management of this species?

The dependence of Flock Bronzewing Pigeons on cracking clay soil habitats renders them vulnerable to intensification of agricultural activities within these land types. Large areas of former habitat especially in the south-east quadrant of their former range are now alienated by intensive agricultural development (Arthington 1996). The area of suitable habitat has been much reduced either by transformation for irrigated agriculture, or rangeland degradation. The stronghold of the species is now confined to the cattle grazing lands of western Queensland and the Barkly Tableland in the Northern Territory. Four priority areas for conservation management can be identified: (i) these include Mitchell grasslands on ashy downs in the western Barkly Tableland; (ii) Mitchell grasslands and bluebush swamps associated with the Playford River system in the eastern Barkly; (iii) Mitchell grasslands north-west of Julia Creek in Queensland near the Flinders and Saxby Rivers; and (iv) floodplains of the Eyre Creek system south of Bedourie in south-west Queensland. Other areas of conservation significance might include the lower Sturt Creek system and Lake Gregory in Western Australia, and the palaeo-channels of the Tanami region in the Northern Territory. It is possible that at any given time a large proportion of the total population of Flock Bronzewing Pigeons may be within individual pastoral stations in these regions (or even within individual paddocks). At present there are no conservation management strategies aiming to address the needs of granivorous birds in these regions. The sole conservation reserve on the Barkly Tableland is both small in area (259 km^2) and is not managed to achieve specific conservation outcomes.

12.4.2 What are the management options for this species?

The first management option for the conservation of this species is to do nothing. Flock Bronzewing Pigeons are not listed under any threat category by the Commonwealth Environment Protection and Biodiversity Act (1999); this thesis has demonstrated that they remain widespread within most of their original range; and large numbers continue to be observed from time to time (e.g. Forsyth 2007). Evidence of ongoing decline in granivorous bird assemblages in northern Australia (Franklin 1999, Franklin *et al.* 2005), and the difficulty of reversing declines when threatening processes are entrenched within the landscape, warns against complacency.

A minimum requirement is to ensure that adequate representative samples of relevant habitats receive protection. Fisher (2001) argued that biodiversity conservation in Mitchell grasslands is best served by multiple small reserves spanning environmental gradients rather than few large reserves. In 1975 there were no areas of Mitchell grassland under reserve or National Park, and grazing exclusion was viewed as antagonistic to proper management of perennial tussocks grasslands which had been maintained as a disclimax community by a disturbance regime of infrequent fire and low intensity grazing by macropods (Everist and Webb 1975). There are now conservation reserves with samples of Mitchell grass communities in the Northern Territory (Connell's Lagoon Conservation Reserve), Queensland (Astrebla Downs and Diamantina National Parks) and New South Wales (Sturt National Park). Nevertheless, in the Northern Territory only 0.5% of the area of Mitchell grasslands is reserved, and reserves in other states are not located in core areas of habitat.

A reserve system of small static reserves surrounded by potentially antagonistic land uses may be insufficient for dispersive taxa such as Flock Bronzewing Pigeons. There is little prospect of substantial addition of lands to the reserve system that would provide habitat on a year round basis. The only valid option is sympathetic management of suitable habitat within the pastoral estate founded on detailed understanding of the ecological requirements of the species. The challenge of conservation management of nomadic granivorous birds such as the Flock Bronzewing Pigeons needs to be met by effective engagement with the pastoral community. How to forge a nexus between conservation biology and the pastoral community is a perplexing issue. However, the Flock Bronzewing Pigeon may be suitable as a flagship species to promote sustainable land management practices and recognition of the importance of biodiversity values on pastoral lands. The implementation of effective measures for conservation of iconic species such as the Flock Bronzewing Pigeon would seem to provide a unique opportunity for the pastoral industry to demonstrate capacity in the ecologically sustainable use of the rangelands.

The overarching objective for management of granivorous birds in pastoral landscapes is to ensure that adequate supplies of seed of preferred food plants are available year round. Processes which lead to simplification of grassland communities such as the spread of introduced pasture grasses (Fairfax and Fensham 2000) diminish the probability that landscapes sustain populations of granivorous birds. Subtle differences in floristics and phenology mean that different habitats may provide seed at different parts of the seasonal cycle, and thus a complex of regional habitats may need to be considered for protection or management. Spatial and temporal variability in rainfall means that conservation measures need to replicated at sufficient sites to minimise the probability of range-wide resource bottlenecks.

I propose a tiered system of conservation management along the lines decribed by Morton *et al.* (1995). This would include diffuse actions throughout the occupied range of the species and systematic planning for actions within core areas of habitat. Pastoralists have the opportunity to manipulate the timing and intensity of grazing in key habitats on a temporary or permanent basis by adjusting stocking rates, the distribution of watering points, and by rotational wet season spelling. The latter is designed to allow recovery of pasture and permit the completion of seeding, and has intuitive appeal as a strategy for the conservation management of granivorous birds in pastoral landscapes, though these benefits have yet to be quantified. Wet season spelling has been suggested as a tool for management of endangered granivores e.g. Black-throated Finch *Poephila cincta cincta* (Anon 2009). Other pastoral practices which defer grazing, such as harvesting dry plant biomass ('hay-bailing') for storage and consumption by stock, may have similar effects. The costs and benefits to both production and biodiversity need to be adequately assessed. Key habitats include Mitchell grass communities on 'ashy downs', peabush (*Sesbania* sp.) swamps, and Queensland bluebush (*Chenopodium auricomum*) swamps.

The second level involves specific management actions in areas of core habitat, perhaps within the four priority areas identified above. This would require detailed knowledge of bird use of habitat units through time, detailed mapping of habitat units, knowledge of the response of habitat units and resource levels within them to varying levels of grazing pressure, and a capacity to temporarily adjust grazing pressure and potentially the extent, timing and frequency of fire. The consequences of management actions could be assessed using spatially explicit decision support tools (e. g. Liedloff *et al.* 2009).

12.4.3 Is there a role for fire in grazed grasslands?

Fire has been widely suppressed in Mitchell grasslands (Wilson 1990) and fire has largely been eliminated as an ecological factor. Prior to occupation by the pastoral industry grasslands would have been subjected to periodic burning following ignition by early wet season storms and deliberate firing by Aboriginal people, though the record of pre-settlement fire patterns in these grasslands is sparse (Fensham 1997). Theoretically burning would have generated a complex mosaic of patches with varying histories of time since last fire and different stages of community response. In the absence of burning this heterogeneity is lost and replaced by a more subdued patterning generated by continuous grazing radiating from fixed watering points. One consequence is that those palatable plants associated with moist habitats or the fringes of wetlands receive high grazing pressure and may be eliminated from local landscapes. The annual grass Channel Millet *Echinochloa turneriani* has largely been extirpated from all but grazing refugia on the Barkly Tableland (Johnson *et al.* 1982, Fleming *et al.* 1983). Responses to fire of Mitchell grasslands flora are poorly known, though *Trichodesma zeylanicum* is known to respond to fire in desert communities (Bird *et al.* 2003). Fire in grazed grasslands will re-distribute grazing pressure towards burned areas: hence unless associated with planned wet season spelling from grazing, any fire may have adverse consequences for soils and vegetation.

A decline in fire frequency has been implicated in the decline of granivorous birds in northern Australia (Franklin 1999). Granivorous birds in northern Australia commonly feed on burnt ground: fire removes the senescent grass layer and exposes seeds on the ground surface (Woinarski 1990). There are few records of Flock Bronzewing Pigeons foraging on burnt ground (Carter 1902, Chisholm 1945, Jaensch pers. comm.), unsurprising given the very low frequency of fire in Mitchell grass habitat.

12.4.4 Is there a weak link in the food chain?

Granivorous birds inhabiting seasonal environments experience annual changes in food resource availability. Seeds available during the dry season may be depleted gradually by consumption by ants, birds and rodents, destruction by fire, or loss by burial until exhaustion by germination after early wet season rainfall. Finches inhabiting savanna woodland in the Top End of the Northern Territory switch diet from seeds of annual grasses in the dry season to seeds of a succession of perennial grasses as they become available throughout the wet season (Dostine and Franklin 2002). Finches require access to a continuous supply of seed from a set of grasses with differing reproductive phenologies to avoid a resource bottleneck. The large-seeded early-seeding perennial grass *Alloteropsis semialata* provides an important bridging link, and has been described as a keystone species in northern Australia (Crowley 2008). In Mitchell grasslands, the foods of Flock Bronzewing Pigeons vary seasonally, though not to the same extent as observed in savanna finches: the relative contributions of seed of main food plants varied seasonally rather than a switch from annual to perennial species. However, there was evidence that seed of *Commelina* species may be important during the wet season. These are large-seeded early seeding annual or perennial herbs found in a variety of habitats, but commonly in moist situations on floodplains (Wheeler 1992). The species *Commelina tricarinata* can be found in association with bluebush swamps on the Barkly Tableland (Brock 2000) and is suspected to be a critical link in the chain of resources required throughout wet season months prior to seed set of the principal dry season food plants. The annual grass *Chionachne hubbardiana* is also suspected to be a critical species throughout the northern portion of the range of Flock Bronzewing Pigeon. Both species produce large, easily harvested seeds (mean dry weight of *C. tricarinata* seeds 12.8 mg; mean dry weight of *C. hubbardiana* kernels 13.6 mg) and both plants are palatable to cattle. Both are potential candidates for weak links in the chain of resources required by Flock Bronzewing Pigeons, at least in the northern Mitchell grasslands. Targeted experiments involving replicated small cage exclosures will elucidate the grazing sensitivity of these species. There is some evidence that bluebush swamps may provide critical habitat during wet season months. Whilst this has yet to be adequately substantiated it is clear that conservation planning needs to be based on knowledge of the full spectrum of resources and habitats required throughout the seasonal cycle. Further data are required on habitat use in wet season months.

12.5 LIMITATIONS OF THIS STUDY AND RECOMMENDATIONS FOR FURTHER STUDY

The limitations of this study include the following:

(1) Foremost was the risk of failing to capture pivotal ecological drivers of this species within the reporting time-frame of this project. This was addressed by seeking data on historic patterns of occurrence from landholder surveys. Surveys provided information on inter-annual patterns of occurrence within the past several decades.

(2) This project focussed mostly on a single site on the Barkly Tableland and there is consequently only limited information from other regions, and the ability to generalise results is constrained. Field work planned for sites within the Channel Country in south-west Queensland in 2006 was abandoned due to the absence of pigeons after failure of summer rainfall in the area in 2005/06.

(3) Expectations that satellite telemetry would provide information on year-round habitat use for several individuals were not met satisfactorily. Telemetry provided new information on previously undescribed aspects of behaviour and movement responses of the species, but not over an extended temporal scale, and not from multiple independent observations. Much further work remains to confirm and substantiate these results. The project succeeded in developing capture methods, and suggestions to improve the post-capture fate of pigeons have been outlined. Solar PTT packages weighing ~5 g will be available in the near future. These devices will greatly enhance the prospects of successfully unravelling the several remaining questions on the nature, timing and extent of movements in this species.

(4) The study did not include an explicit test of management interventions to assist in the conservation management of this species. The large spatial scale within which this species

operates effectively precludes experimentation. I used data from existing biodiversity studies within grazing experiments to assess the effects of grazing on known food plants. The difficulties associated with interpreting data from unreplicated grazing trials have been discussed.

Recommendations for further study include:

(1) Investigate variation in year-round resource and habitat requirements at additional key sites for this species. The most significant priority at this stage is adequate understanding of resource requirements in the Channel Country region.

(2) Examine interactions between seed resource dynamics and movement patterns at sites with a different floristic base e.g. northern and southern parts of Mitchell grass area of Queensland.

(3) Conduct experimental studies using small exclosures on effects of grazing on known food plants especially those used at times of potential food bottlenecks.

(4) Conduct experimental studies on effects of fire on seed production on known food plants, and interactions between fire and post-fire grazing on seed production of known food plants.

(5) Establish and maintain a long-term monitoring network within the pastoral community to assess population trends of high profile wildlife species including Flock Bronzewing Pigeons.

(6) Communicate results of this project with recommendations for management to participant landholders and where appropriate to relevant pastoral companies, regional land care groups and state land management agencies.

(7) Collaborate with landholders to develop management practices and programs that are favourable to the long-term and large-scale conservation of Flock Bronzewing Pigeons.

12.6 CODA

The sight of large wheeling flocks of native pigeons is a highlight and a quintessential part of the grasslands and open landscapes of outback Australia. Witnessing the maelstrom of thousands upon thousands of pigeons intent on drinking before dusk under the vast evening sky is both an inspiring and unnerving experience. To me they represent the spirit of a landscape that once recognised, is impossible to forget. May we not forget nor neglect the places that sustain this spirit of wildness and wilderness.

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Appendix 1: OBSERVATIONS ON MASS DRINKING BEHAVIOUR IN FLOCK BRONZEWING PIGEONS

INTRODUCTION

Regular visits to water for the purpose of drinking form part of the daily routine of many birds in arid and semi-arid regions. Patterns of drinking behaviour of 'desert' birds in Australia, including the Flock Bronzewing Pigeon, have been previously described (Fisher *et al.* 1972). This study identified that birds belonging to the predominantly granivorous families Columbidae, Psittacidae and Estrildidae are highly dependent on free water. Daily patterns of drinking varied with ecological correlates including body size and foraging distance from water. Flock Bronzewing Pigeons displayed two well defined peaks of drinking activity, in the early morning and late afternoon; a pattern shared with three genera of platycercine parrots (Fisher *et al.* 1972), and the estrildid finch Pictorella Mannikin *Heteromunia pectoralis* (Evans *et al.* 1985). Some species have largely crepuscular drinking habits, and visit water to drink completely or partially before sunrise and after sunset (Bourke's Parrot *Neopsephotus bourkii* and Common Bronzewing Pigeon *P. chalcoptera*). Small columbids such as Diamond Dove *Geopelia cuneata*, and estrildid finches such as Zebra Finch *Taeniopygia guttata* drink throughout the day. Aside from the observations of Fisher *et al.* (1972), aspects of behaviour associated with drinking in Flock Bronzewing Pigeons are briefly described by MacGillivray (1901, 1914, 1932), Marshall and Drysdale (1962), Schmidt (1967) and Lindsey (1995). The general pattern of behaviour is as follows. Visits to water for drinking are largely confined to the hours soon after sunrise and prior to sunset: birds are rarely seen in the vicinity of water in the intervening period. MacGillivray (1932) observed morning drinking between 7:45 a.m. and 9:00 a.m. and afternoon drinking between 4:40 and 6:00 p.m.; whilst Schmidt (1967) noted Flock Bronzewing Pigeons flying to water about 7:00 a.m. and 6:00 p.m. Arriving flocks initially land at a distance from water. MacGillivray (1932) noted that they firstly settle "*in grass two hundred yards from the water*". Later arriving flocks congregate with earlier arrivals to form one or more large flocks (Figure 1). After a period of 15-30 minutes birds take flight and engage in coordinated mass circling flights, reminiscent of domestic pigeons, around the drinking site. This behaviour was noted by MacGillivray (1932) and Schmidt (1967), and illustrated in Marshall (1965). These flights can last for several minutes and usually end with the flock resuming a position on the ground at a similar distance from water. There may be several such mass flights before the flock lands to drink: at these times the birds usually head into the wind and can be highly selective where drinking occurs within the periphery of the water body. They can drink from the surface of the water whilst floating (MacGillivray 1932) (Figure 2). Drinking can be extremely rapid and last no more than a few seconds, after which they depart immediately. Variations on this general pattern were frequently observed. For example, on a number of occasions they were observed to land in grass stubble approximately 50 m from a temporary pool in a flooded borrow-pit and to walk to the water's edge.

This pattern of behaviour strongly resembles mass drinking flights observed in several members of the charadriiform family Pteroclididae, or sandgrouse (Maclean 1968, Ward 1972). Sandgrouse occupy an ecological niche similar to that of Flock Bronzewing Pigeons: both are granivores of semi-arid regions and exploit pulses of seed resources which are spatially and temporally unpredictable (Lloyd *et al.* 2001).

This study reports the results of observations on the drinking habits of Flock Bronzewing Pigeons at bores on the Barkly Tableland over a twelve month period from 2006-2007, and considers the functional significance of mass drinking behaviour in this species.

Figure 1 Flock Bronzewing Pigeons near turkey-nest, Coorabulka station, Queensland.

Photo by G. Chapman.

Figure 2 Flock Bronzewing Pigeons drinking at turkey-nest dam, Coorabulka Station, Queensland.

Photo by G. Chapman.

METHODS

The study was conducted on Helen Springs Station on the Barkly Tableland in the Northern Territory. The station homestead (18.434°S 133.874°E) is approximately 140 km north north-west from the township of Tennant Creek. On pastoral stations cattle are reliant on water supplied from artesian storage for drinking. Artesian water is pumped into earth dam structures known colloquially as turkey-nest dams (Figures 3 and 4); from these structures water is gravity fed under the control of float valves to stock troughs. Artificial waters such as turkey-nest dams provide the focus for the daily drinking activities of water dependent fauna.

Counts were conducted at bore 4 (18.116°S 134.439°E) in paddock 4 (n=22) and at bore 9 (18.343°S 134.436°E) in Glenroy paddock (n=8) from a vehicle at a distance of approximately 150 m from the water on the western side to prevent interference from the afternoon sun. Morning counts (n=5) commenced at sunrise and lasted approximately three hours; afternoon counts (n=25) commenced approximately two hours prior to sunset until sunset. On each occasion the size of arriving groups of Flock Bronzewing Pigeons was recorded within one minute intervals. Smaller groups <20 individuals were counted where possible; larger groups >20 were estimated using multiples of 10 individuals. Counts in both the morning and evening of the same day were conducted on three occasions (22nd Sep, 8th Nov and 1st Dec 2006): for these counts data are presented as percentage of daily total within fifteen minute intervals. On all occasions counts are of numbers of birds arriving rather than actually drinking: most drinking occurred within the turkey-nest and could not be directly observed.

The following parameters were derived to describe the patterns of arrival: numbers per minute were summed to provide a survey total; the median time of arrival was estimated from percentage cumulative counts; the time taken for arrival of 90% of the total number of arriving birds per survey was calculated as the difference between the arrival of 5th and 95th percentile of the cumulative count; and the total duration of arrivals was calculated as the difference in minutes between the time of the first and last arrival. All data are expressed in relation to time since or prior to sunrise or sunset. These times were recorded in the field at the time of the survey. The timing of behaviours such as circling flights and peak drinking activity were recorded.

Variation in the size of groups arriving at water was examined using maximum group size per minute and pooled data for five morning counts and seven afternoon counts in late 2006. The relationship between arrival parameters and daily temperature was examined using Pearson product-moment correlation in the software package R (R Core Development Team 2008), and temperature data including maximum daily temperature, minimum daily temperature, and temperature at 9:00 a.m. and 3:00 p.m. from Brunette Downs Station from the Bureau of Meteorology.

Figure 3 Turkey-nest dam on open Mitchell grasslands, Brunette Downs Station, Northern Territory.

Figure 4 Flock Bronzewing Pigeons flying over turkey-nest dam, Helen Springs Station, Northern Territory.

RESULTS

Daily patterns of drinking

There are well-defined peaks in daily drinking activity (Figure 5) in the early morning and late afternoon. Counts were not conducted continuously throughout the day, and some birds may have arrived to drink water in the intervening period, though the number of birds involved would be negligible. On the three days with both morning and afternoon counts, the total number of estimated daily drinking visits varied from 1,748 to 2,010, and the percentage of afternoon drinking visits varied from 39.6% to 55.8%. Further, the percentage of visits in activity peaks increased from 25.0% to 44.4% (Table 1). These results are consistent with the hypothesis that the probability of birds drinking in both morning and afternoon increases with temperature.

Patterns of arrival in late dry season 2006

In the late dry season of 2006 Flock Bronzewing Pigeons commenced arriving between 7-11 minutes after sunrise (mean 9, n=5); in the late afternoon pigeons commenced arriving 60-105 minutes prior to sunset (mean 75, n=7) (Table 2). Five of these observations occurred within the range 60-69 minutes prior to sunset. Patterns of arrival tend to be highly similar between consecutive days, with birds arriving at near identical times, but there are substantial differences between morning and afternoon periods. The mean of the median times of arrival was 74 minutes (range 66-78, *n*=5) in the morning, and 44 minutes (range 40-49, *n*=7) in the afternoon. The mean time taken for arrival of between 5-95% of the total number of birds was 114 minutes (range 98-134, *n*=5) in the morning, and 27 minutes (range 22-33, *n*=7) in the afternoon. Lastly, the mean total duration of arrivals was 171 (range 166-175, *n*=5) in the morning, and 70 minutes (range 54-104, *n*=7) in the afternoon.

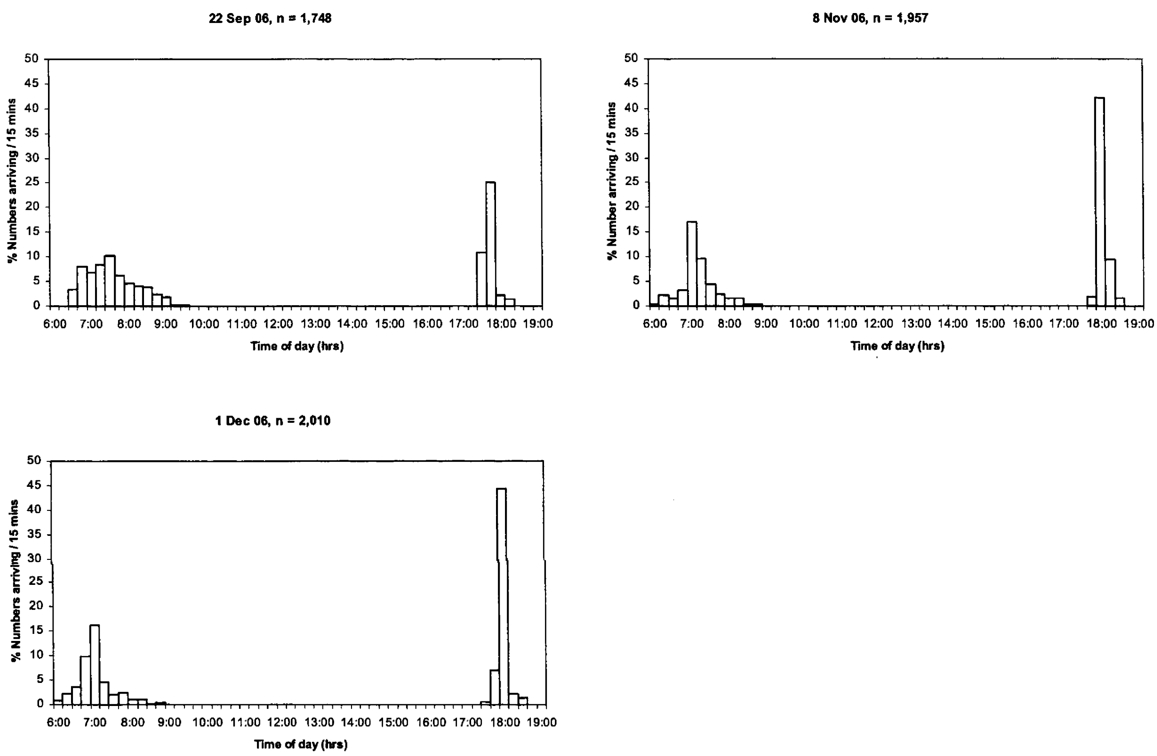

Figure 5 Numbers of Flock Bronzewing Pigeons arriving within fifteen minute intervals in hours following sunrise and prior to sunset on 22nd September 2006, 8th November 2006 and 1st December 2006 at bore 4, Helen Springs Station.

Numbers are expressed as % total birds per day.

Table 1 Summary of survey results from counts in morning and afternoon on three days in late 2006.

Date	Max temp °C	a.m.	p.m.	Total	% pm	Peak interval (% nos)
22 Sep 06	35.3	1,056	692	1,748	39.6	25.0
8 Nov 06	40.4	879	1,078	1,957	55.1	42.1
1 Dec 06	43.9	889	1,121	2,010	55.8	44.4

Table 2 Parameters describing patterns of arrival and behaviours prior to drinking of Flock Bronzewing Pigeons at bores on Helen Springs Station, Barkly Tableland, Northern Territory.

Date	A/M	Site	Drinking	Count total	First arrival	Median	90% interval	Total interval	Commence flight	% present commence flight	# present commence flight	Drinking peak	% present drinking peak
22-Sep-06	M	Bore 4	Yes	1,056	7	66	134	175	70	52.5	554	133	91.2
08-Nov-06	M	Bore 4	Yes	879	11	75	109	170	86	73.3	644	150	98.0
09-Nov-06	M	Bore 4	Yes	1,098	11	78	127	167	88	65.8	722	148	90.1
01-Dec-06	M	Bore 4	not seen	889	8	75	104	176	87	74.4	661		
02-Dec-06	M	Bore 4	Yes	1,050	10	77	98	166	92	75.9	797		
21-Sep-06	A	Bore 4	Yes	744	66	45	30	64	47	36.6	272	31	91.5
22-Sep-06	A	Bore 4	Yes	692	60	45	33	54	39	78.8	545	16	96.2
26-Sep-06	A	Bore 4	Yes	470	66	43	30	60	39	69.8	328	29	92.1
07-Nov-06	A	Bore 4	Yes	918	93	40	24	90	38	65.7	603		
08-Nov-06	A	Bore 4	Yes	1,078	64	40	25	61	39	56.8	612		
30-Nov-06	A	Bore 4	Yes	1,118	69	46	28	59					
01-Dec-06	A	Bore 4	Yes	1,121	105	49	22	104	39	93.2	1,045	30	95.5
28-Feb-07	A	Bore 4	No	83	92	52	44	68					
02-Mar-07	A	Bore 4	No	105	98	74	50	77					
17-Apr-07	A	Bore 4	No	289	87	48	44	77					
19-Apr-07	A	Bore 4	No	333	84	55	33	74					
22-Apr-07	A	Bore 9	Yes	502	91	61	37	75	55	58.8	295		
23-Apr-07	A	Bore 9	Yes	544	83	60	49	74	59	56.8	309		
22-May-07	A	Bore 4	No	153	68	30	36	63					
23-May-07	A	Bore 4	No	128	58	38	23	45					
26-May-07	A	Bore 9	Yes	216	49	36	21	41	32	62.5	135	18	98.6
27-May-07	A	Bore 9	Yes	338	43	32	11	29	28	95.6	323	10	100.0
06-Jul-07	A	Bore 4		0									
07-Jul-07	A	Bore 9	Yes	127	39	39	17	17					
08-Jul-07	A	Bore 9	Yes	248	45	43	8	25					

Table 2 cont.

Date	A/M	Site	Drinking	Count total	First arrival	Median	90% interval	Total interval	Commence flight	% present commence flight	# present commence flight	Drinking peak	% present drinking peak
10-Jul-07	A	Bore 4	No	1	49								
11-Sep-07	A	Bore 4	No	10	30	29	11	11					
12-Sep-07	A	Bore 9	Yes	113	42	39	7	21					
13-Sep-07	A	Bore 9	Yes	86	57	48	12	38					
15-Sep-07	A	Bore 4		0									

The size of groups arriving to drink varied between morning and afternoon periods (Table 3). The mean group size in morning counts was 3.8 individual birds, whereas the mean group size in afternoon counts was 6.4 individuals. The percentage of groups with >5 individuals was 17.0% in morning counts, and 30.8% in afternoon counts. The maximum group size per minute varied within and between morning and afternoon sessions (Figure 6). Groups in morning counts rarely exceeded 20 individuals at any time and rarely exceeded 5 individuals 90 minutes after sunrise; whereas maximum group size in afternoon counts was rarely less than 20 individuals, but declined abruptly between 45-30 minutes prior to sunset. Morning counts include an anomalous record of a single flock of 70 individuals arriving more than two hours after sunrise.

Table 3 Percent frequency of group sizes of arriving Flock Bronzewing Pigeons in pooled morning and afternoon counts in late 2006.

Group size	% freq a.m.	% freq p.m.
1	35.8	35.6
2	26.1	15.2
3	9.1	8.8
4	7.3	5.8
5	4.7	3.8
6 to 10	10.6	14.0
11 to 15	2.9	5.7
16 to 20	2.3	4.4
21-30	0.9	4.0
31-50	0.2	2.0
51-75	0.1	0.6
76-100		0.1
Total individuals	4,973	6,141
Total groups	1,320	962
Mean group size	3.8	6.4

Timing of approach to water and drinking

In the late dry season of 2006, assembled flocks at watering points commenced mass pre-drinking flights an average of 85 minutes (range 70-92, *n*=5) minutes after sunrise, and 40 minutes (range 38-47, *n*=6) prior to sunset. The times of initiation of afternoon pre-drinking flights were remarkably consistent between days (Table 2). In both the morning and afternoon, pre-drinking flights commenced after arrival of approximately two thirds of the total number of arriving birds (68.4% in morning, and 66.8% in afternoon). The peak of drinking activity occurred at an average of 144 minutes after sunrise (range 133-150, *n*=3) after the arrival of 93.1% of the total number of arriving birds, and at 27 minutes prior to sunrise (range 16-31, *n*=4) after the arrival of 93.8% of the total number of arriving birds.

a.) b.)

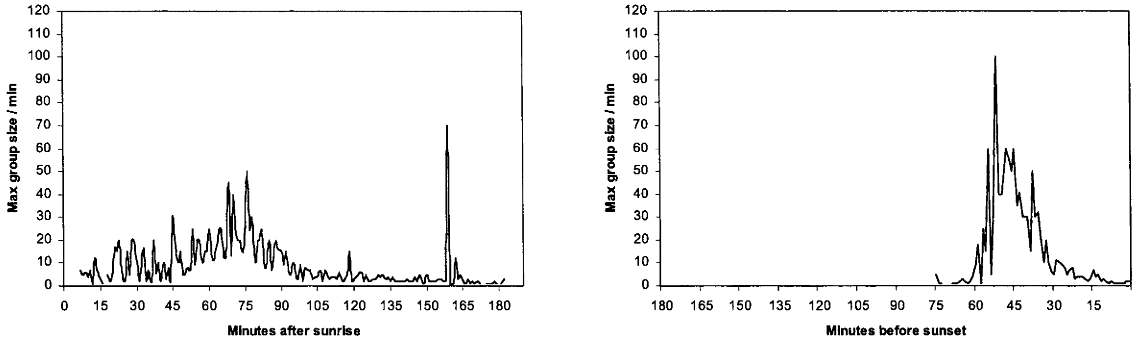

Figure 6 Maximum group size per minute a.) after sunrise and b.) before sunset, of Flock Bronzewing Pigeons arriving to drink at bore 4, Helen Springs Station, Barkly Tableland, Northern Territory.

Data pooled from five morning counts and seven evening counts between 21st September 2006 and 2nd December 2006.

a.) b.)

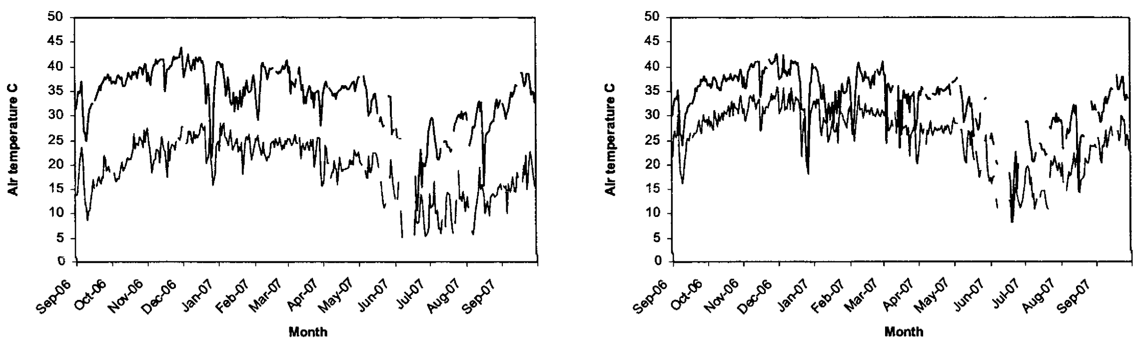

Figure 7 Daily variation in a.) maximum and minimum air temperature (°C), and b.) air temperature recorded at 9:00 a.m. and 3:00 p.m. from 1st September 2006 to 30th September 2007.

Effect of variation in temperature on drinking patterns

Air temperature fluctuated on a daily and seasonal basis (Figure 7). In the late dry season of 2006 total afternoon count of arriving birds was positively correlated with maximum temperature; the time taken for arrival of between 5-95% of birds was negatively correlated with maximum temperature (Table 4, Figure 8). More birds were counted on hotter days, and the timing of visits was compressed on hotter days.

Temperature was positively correlated with the time of first arrivals, median time of arrival, duration of 5-95% of arrivals, and total arrivals of all afternoon counts in both years (Table 4, Figure 9). Birds tended to arrive earlier on hotter days, and take longer to arrive; this result contradicts previous results using only 2006 data.

Table 4 Results of correlation analyses of parameters describing patterns of arrival of Flock Bronzewing Pigeons and temperature variables for data from afternoon counts in 2006, and all afternoon counts in 2006 and 2007.

Afternoon counts late dry season 2006			
Variable 1	**Variable 2**	***r***	**P value**
Count total	Max temp	0.804	0.029
	Temp 9 a.m.	0.922	0.003
	Temp 3 p.m.	0.824	0.023
Duration 90% arrivals	Max temp	-0.814	0.026
	Temp 9 a.m.	-0.870	0.011
	Temp 3 p.m.	-0.803	0.029
All afternoon counts 2006, 2007			
Time first arrival	Max temp	0.643	0.002
	Min temp	0.784	<0.001
	Temp 9 a.m.	0.634	0.004
	Temp 3 p.m.	0.667	0.002
Time median arrival	Min temp	0.535	0.018
Duration 90% arrivals	Min air temp	0.477	0.039
Duration all arrivals	Max temp	0.667	0.001
	Min temp	0.752	<0.001
	Temp 9 a.m.	0.668	0.002
	Temp 3 p.m.	0.686	0.001

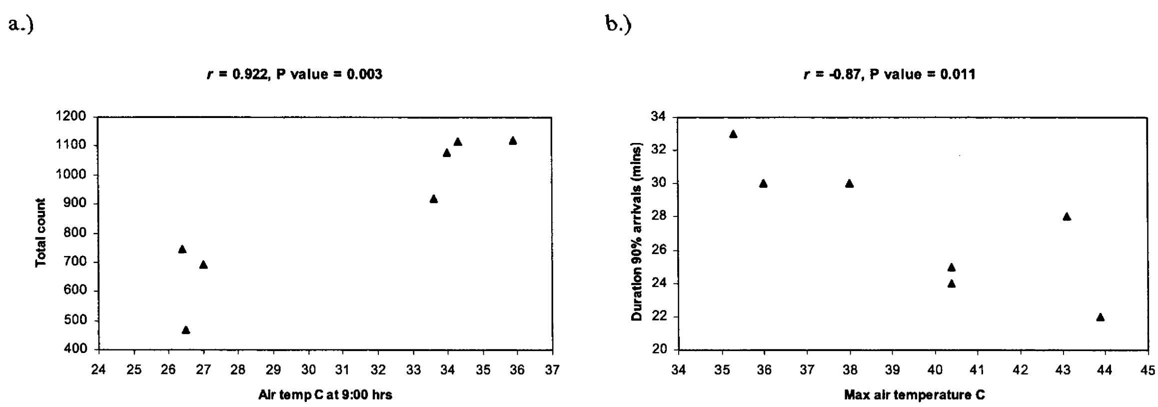

Figure 8 a.) Relationship between total counts in 2006 and 9 a.m. air temperature, and b.) relationship between duration of 90% of arrivals and maximum air temperature.

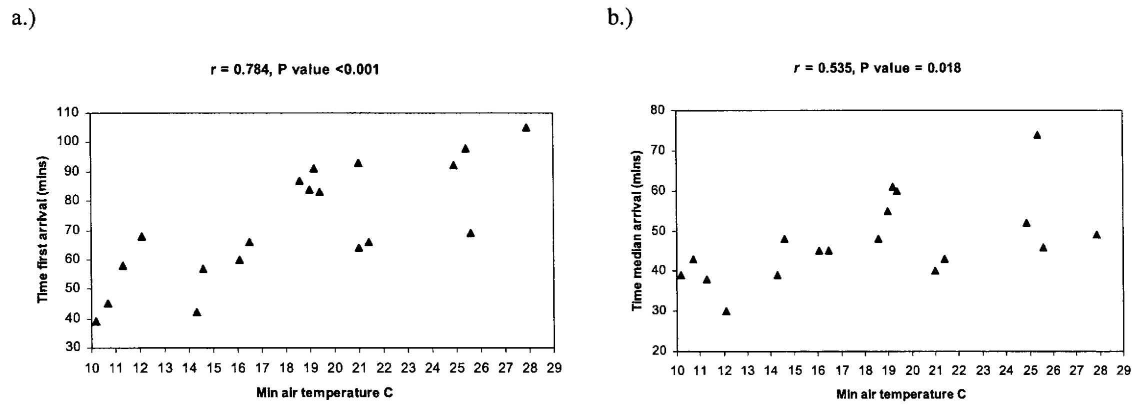

Figure 9 a.) Relationship between time of first arrival and minimum air temperature, and b.) median time of arrival and minimum air temperature.

DISCUSSION

These results are consistent with general observations in the literature and the quantitative descriptions of Fisher *et al.* (1972). The daily routine of Flock Bronzewing Pigeons includes visits to water for drinking in the early morning and late afternoon, though the extent to which all individuals drink twice per day is unclear. There were no marked birds in this study and the frequency of drinking of individual birds was not described. The data is consistent with the suggestion of Fisher *et al.* (1972) that birds are more likely to drink in the afternoon as daily temperature increases.

Drinking of Flock Bronzewing Pigeons involves a number of behaviours including near synchronous arrival at water, formation of large aggregations near water, synchronous mass pre-drinking flights, extreme caution on approach to water and rapid departure following drinking (Table 5). After arrival at water birds defer drinking for some time: estimated at 70 minutes in the morning, and 17 minutes in the afternoon. Why drinking should be deferred for such a considerable period in the morning is an interesting question. Morning arrivals consist mostly of small groups from night roosting sites scattered throughout the grasslands; in the afternoon birds arrive in larger groups which may have been formed by amalgamation of feeding flocks during the day or of groups en route to the drinking site. In both morning and afternoon drinking does not take place until the arrival of the majority (>90%) of incoming birds.

Functional significance of mass drinking flights

There are two primary hypotheses to explain gregariousness in birds: protection from predators (Lack 1968), and to increase the efficiency of locating unevenly distributed food resources (Ward and Zahavi 1973). These authors suggest a relationship between roosting habits and foraging habits of birds: communally roosting species tend to feed in flocks on unevenly distributed food resources. Communal roosts may act as information-centres to facilitate food finding by individuals.

Table 5 Summary of parameters of patterns of drinking from late 2006 observations.

Parameter	a.m .	% total flock	p.m.	% total flock
First arrival	9		75	
Median arrival	74		44	
Duration 5-95% arrivals	114		27	
Pre-drinking flights	85	68%	40	67%
Drinking peak	144	93%	27	94%
Group size	mostly small		some large	

Several species of the charadriiform family Pteroclididae (sandgrouse) exhibit traits of drinking behaviour which strongly resemble those of Flock Bronzewing Pigeons (Maclean 1968). For example, the Namaqua Sandgrouse *Pterocles namaqua* has synchronised mass flights to water, constant time of arrival at drinking sites, and gather in large flocks before drinking (Ward 1972). Flocks of the Spotted Sandgrouse *P.burchelli* sometimes circle for several minutes before landing to drink, and can do so from the surface of the water (Maclean 1968). Neither form communal roosts, and roost in small groups in response to the abundance of nocturnal ground predators. The formation of regular assemblages at drinking sites may facilitate exchange of information to members of the flock on the distribution of food resources (Ward 1968, Ward and Zahavi 1973).

Avian predators are commonly present, indeed concentrated, at watering sites and present a hazard to birds seeking water (Cade 1965). The behavioural adaptations observed in Flock Bronzewing Pigeons may partly be a response to minimise the effectiveness of predators. There are few observations of interactions between Flock Bronzewing Pigeons and raptors (MacGillivray 1932, Olsen and Olsen 1986, McAllan 1996, Read *et al.* 1996); during this study Flock Bronzewing Pigeons were harassed by Black Falcons *Falco subniger* on only two occasions, and predation pressure on adult birds is probably low. Zahavi (1971) proposed that the anti-predator adaptations of communal roosting were secondary, and follow from the increase in predation pressure when birds assemble for the benefit of social food-finding. It seems likely that the behaviours associated with drinking in the Flock Bronzewing Pigeon and sandgrouse species are convergent adaptations to the same problem, i.e. finding spatially variable food resources in semi-arid landscapes.

SUMMARY OF FINDINGS AND CONCLUSIONS

Small flocks of Flock Bronzewing Pigeons from dispersed feeding or roosting areas on open grassland converge to form one or more large flocks at preferred watering sites twice daily. These aggregations may involve thousands, or even tens of thousands of individuals. Counts of the number of arriving Flock Bronzewing Pigeons, and observations on their behaviour, were conducted on 30 occasions between September 2006 and September 2007, during hours after sunrise (n=5), and hours prior to sunset (n=25).

The timing of arrival of birds at water, and behaviours associated with drinking, are highly synchronised. Patterns of arrival differed between morning and afternoon: in late 2006 the mean arrival time was 9 minutes after sunrise (range 7-11, n=5) and 75 minutes before sunset (range 60-105, n=7); the median arrival time was 74 minutes (range 66-78, n=5) after sunrise and 44 minutes (range 40-49, n=7) before sunset; the time taken for arrival of 5-95% of all birds was 114 minutes (range 98-134, n=5) in the morning and 27 minutes (range 22-33, n=7) in the afternoon. Patterns of arrival varied seasonally and were correlated with temperature. The size of flocks approaching water differed between the morning and afternoon periods.

Generally, small flocks arriving at the watering site gather on the ground distant from water in the near vicinity of previous arrivals, and do not immediately approach the water to drink. After the arrival of the majority of birds, the flock performs repeated circling flights around the watering point prior to drinking either whilst floating on the water surface, or after landing near the water's edge and walking to the edge to drink. Individuals complete drinking within seconds and rapidly depart the area. Some aspects of drinking behaviours of Flock Bronzewing Pigeons have been described previously but have not been quantified.

The functional significance of synchronised mass drinking flights in Flock Bronzewing Pigeons has not been considered. Parallel behaviours in several members of the charadriiform family Pteroclididae (sandgrouse) are hypothesised to facilitate exchange of information on the distribution of spatially dispersed seed resources in unpredictable arid environments. Both Flock Bronzewing Pigeons and sandgrouse do not form large feeding flocks, or communal roosts, and regular daily aggregations prior to drinking provide an opportunity for communal information exchange.

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Appendix 2: INTER- AND INTRA-ANNUAL VARIATION IN ABUNDANCE OF FLOCK BRONZEWING PIGEONS AT A SITE ON THE BARKLY TABLELAND, 2005-2007

INTRODUCTION

There are two peaks of drinking activity in the Flock Bronzewing Pigeon (MacGillivray 1932, Fisher *et al.* 1972), in the early morning in hours after sunrise and in late afternoon prior to sunset. Their daily routine includes commuting flights between distant roosting or foraging areas on the open grassland plains, and drinking sites. These watering points are frequently artificial waters provided as storage dams to supply the drinking needs of domestic stock. This behaviour provides an opportunity to detect their local presence and to quantify local abundance: there are few alternative approaches to population assessment in this cryptic species. Birds present at or near bores on a large pastoral station were recorded on a near daily basis by a resident staff member of Alexandria Station from mid 2005 to late 2007. This is the first attempt to document temporal variation in Flock Bronzewing Pigeon numbers. Counts of individuals converging at watering points have previously been adopted in studies of granivorous birds including Gouldian Finch (Evans and Bougher 1987) and Namaqua Sandgrouse (Lloyd *et al.* 2001).

This chapter seeks to answer the question: What are the inter- and intra-annual patterns of abundance of Flock Bronzewing Pigeons in Mitchell grasslands in the Barkly region?

METHODS

The study was conducted on Alexandria Station (19.059°S 136.708°E) on the Barkly Tableland in the Northern Territory. Alexandria is situated in the eastern Barkly Tableland, north of the Barkly Highway and extends in part to the Northern Territory-Queensland border: the station homestead is approximately 218 km north-west of the Queensland township of Camooweal. Alexandria is owned by the North Australian Pastoral Company and covers an area of 16,118 km^2 and carries an estimated cattle herd of 55,000 depending on the season. Most of the pastoral bores used in this study are situated within five large paddocks (Farr's, Double bluebush, Plain bore, East Ranken and West Ranken) which cover a combined area of 3,155 km^2. Vegetation in the study area is dominated by *Astrebla pectinata* (Barley Mitchell grass) grassland (vegetation type 96 of the Northern Territory vegetation survey map, (Wilson *et al.* 1990)), and *Astrebla* (Mitchell Grass) grassland understorey (vegetation type 26 of the Northern Territory vegetation survey map (Wilson *et al.* 1990)).

Data on numbers of Flock Bronzewing Pigeons at bores in the study area on Alexandria station were collected by Mr Ivan O'Donahoo on 282 days over a three year period from 2005 to 2007. Mr O'Donahoo is an accomplished birdwatcher and is employed by Alexandria Station as a bore-runner on the Ranken portion of the property. Over two days the bore-runner traverses a fixed route to inspect stock dam water levels and maintain pumps and other equipment for providing water for cattle. He inspects 10 and 19 bores on consecutive days of the bore run, covering distances of 247 and 271 kms on each day. On each day the route and consequently the timing of visits to an individual bore is more or less constant. Numbers of Flock Bronzewing Pigeons seen at bores were recorded on a daily basis where possible, except for interventions by illness, work commitments, absence due to leave or when heavy rainfall prevented access. In 2005 data were collected from 6th June to 12th December; in 2006 from 12th March to 6th December; and in 2007 from 9th February to 30th October. In general, days when Flock Bronzewing Pigeons were absent at all bores were not recorded. The bore-run was completed prior to the late afternoon peak of drinking activity by Flock Bronzewing Pigeons. On each occasion at each bore when Flock Bronzewing Pigeons were present, data were collected on each bore name, estimated numbers and time of visit in a data notebook provided for that purpose. The number of individuals in large flocks >100 could only be estimated.

The time of bore visits was corrected for variation in the daily time of sunrise, and expressed as 'minutes after sunrise'. The times of sunrise for coordinates 19°04'S and 136°42'E were estimated using the National Mapping Division's 'sunrisenset' program version 2.2, available on the Geoscience Australia web site. Times of sunrise varied by 81 minutes, from 5:36 a.m. on 21st November to 6:57 a.m. on 16th July (Figure 1). The time for each observation expressed as 'minutes after sunrise' is shown for all observations as a frequency histogram.

Monthly rainfall data for Alexandria Station was obtained from Bureau of Meteorology records through the Rainman software package version 4.3.0386. Average total of seasonal rainfall (July-June) at Alexandria Station is 397 mm, based on 121 years of rainfall records. Seasonal rainfall totals were 278 mm in 2004/05; 634 mm in 2005/06; and 418 mm in 2006/07; the percentage ranks of seasonal rainfall totals were 29.8%, 90.9% and 66.1% respectively. Daily rainfall data for recent years was obtained courtesy of the station manager (Figure 2).

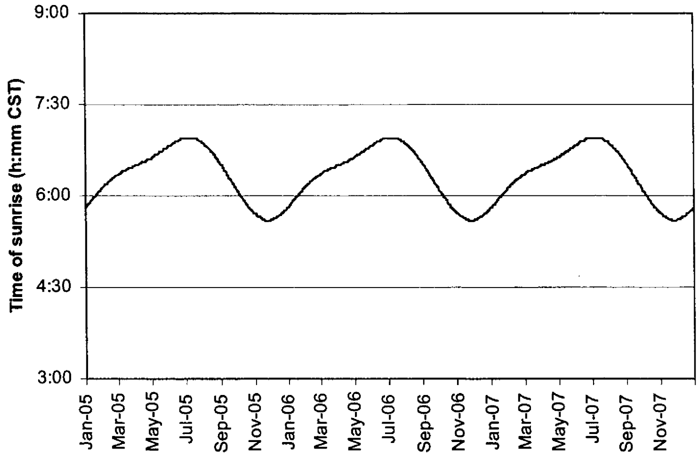

Figure 1 Daily variation in time of sunrise (Central Standard Time) for Alexandria Station.

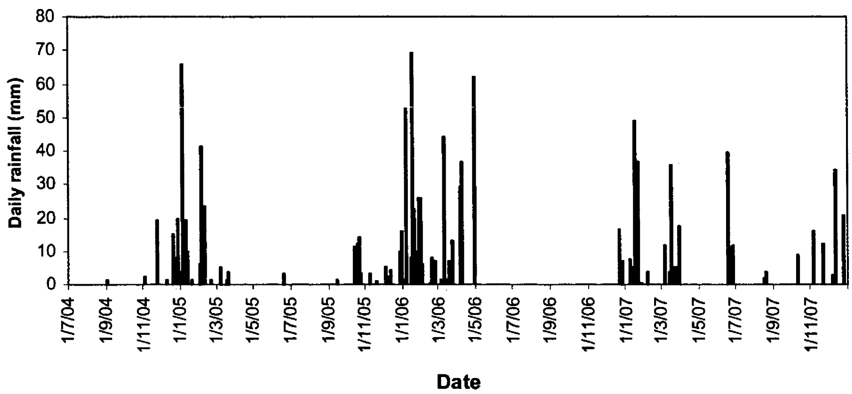

Figure 2 Daily rainfall data for Alexandria Station from 1st July 2004 to 31st December 2007.

Temporal patterns of abundance are examined by summarising data on an annual and monthly scale. Numbers of Flock Bronzewing Pigeons counted, or estimated, at pastoral bores were summed and standardised by the number of survey days. Results are presented for analyses of all bores combined; for East Ranken and West Ranken bore-runs separately; and for individual bores contributing >5% of the total count.

Monthly data on gross primary productivity (GPP mol CO_2 m^{-2} day^{-1}) of the raingreen component of vegetation were used to examine differences in patterns of plant productivity. Data were derived from NDVI (Normalized Difference Vegetation Index) imagery captured by sensors borne on the MODIS satellite. Details of the calculation of GPP of the raingreen component of vegetation are presented elsewhere. The maximum GPP per pixel was calculated from separate grids for GPP in April in each year from 2001 to 2007, using the function max(grid1, grid2....) in ArcGIS. Monthly variation in GPP within minimum convex polygons enclosing the West Ranken and East Ranken bore-runs were calculated from 100 random points within each bore-run.

Caveats and interpretation

These counts are instantaneous estimates of the number of Flock Bronzewing Pigeons present at the time of the visit by the bore-runner, and not cumulative tallies of the number arriving to drink. The number of birds present is dependent on the time of day: at a given site numbers will be low soon after sunrise, build during the following hours as flocks aggregate to drink, and then decline sharply as bird depart. This time dependence presents difficulties when comparing patterns of abundance between sites, or sets of sites, and data need to be interpreted with caution.

The absence of Flock Bronzewing Pigeons at individual bores was not recorded; this constrains the ability to model patterns of abundance, or of frequency of occurrence, without making assumptions on the nature of lack of detection. The size of large aggregations of Flock Bronzewing Pigeons constitute no more than rough guesses of the number of birds involved; where possible flock size was estimated using multiples of 100 birds. All data were collected by the same individual, and bias in estimates is consistent throughout the study period.

RESULTS

Timing of daily observations

Flock Bronzewing Pigeons were mostly recorded in the hours immediately after sunrise (median 137 minutes, range 8-586). Most records of Flock Bronzewing Pigeons (73%) occurred less than 3 hours after sunrise, and approximately 23.3% occurred between 2-2.5 hours after sunrise (Figure 3). The majority of records occurred prior to noon (n=723, 88.3%), and relatively few (n=96, 11.7%) after this time. The latest record occurred at 4:10 p.m. The bore-runs were completed prior to the late afternoon visits to water by Flock Bronzewing Pigeons.

Temporal patterns of abundance

There were 821 records of Flock Bronzewing Pigeons over the study period on 282 separate days, on which a total of 203,683 Flock Bronzewing Pigeons were recorded (Table 1). Flock Bronzewing Pigeons were recorded at 30 bores; only 6 bores individually contributed more than 5% of the total number of birds counted over the three years of the study. The mean count per day varied from 215 in 2005; to 1,275 in 2006 and 259 in 2007. The number of Flock

Bronzewing Pigeons present at bores differed between the separate bore-runs, and was higher on the West Ranken bore-run (Tables 2 and 3).

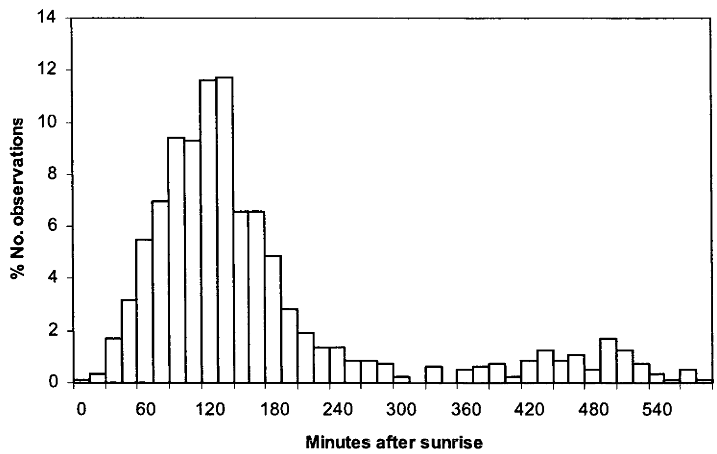

Figure 3 Percentage frequency of number of observations in relation to time after sunrise.

Table 1 Summary of results from surveys of Flock Bronzewing Pigeon numbers at bores on Alexandria Station, Northern Territory.

Year	Total count	# records	# days	Mean count/day	Start	Finish
2005	6,665	47	31	215	6 Jun 05	12 Dec 05
2006	165,726	468	130	1,275	2 Mar 06	6 Dec 06
2007	31,292	306	121	259	9 Feb 07	30 Oct 07
Total	203,683	821	282			

Table 2 Summary of results from surveys of Flock Bronzewing Pigeon numbers at bores on the East Ranken bore-run, Alexandria Station, Northern Territory.

Year	Total count	# records	# days	Mean count/day	Start	Finish
2005	1,209	16	12	101	7 Jun 05	12 Dec 05
2006	48,735	116	56	870	2 Mar 06	6 Dec 06
2007	8,142	125	62	131	12 Feb 07	30 Oct 07
Total	58,086	257	130	447		

Table 3 Summary of results from surveys of Flock Bronzewing Pigeon numbers at bores on West Ranken bore-run, Alexandria Station, Northern Territory.

Year	Total count	# records	# days	Mean count/day	Start	Finish
2005	5,110	19	11	465	6 Jun 05	30 Nov 05
2006	99,765	185	65	1,535	3 Mar 06	5 Dec 06
2007	22,720	155	57	399	9 Feb 07	20 Oct 07
Total	127,595	359	133	959		

The numbers of Flock Bronzewing Pigeons present at bores increased throughout the dry season in 2006 and 2007, and fell dramatically between the end of the late dry season and the start of the following dry season (Figure 4). Increases in number may be due to changes in the pattern of dispersion of birds, recruitment by breeding, or immigration. The decline in the wet season may be largely due to emigration from the area initiated by rainfall. There is a minor mid-dry season decline in numbers in September 2006, though whether this has a biological basis or is an artefact of data collection is unknown.

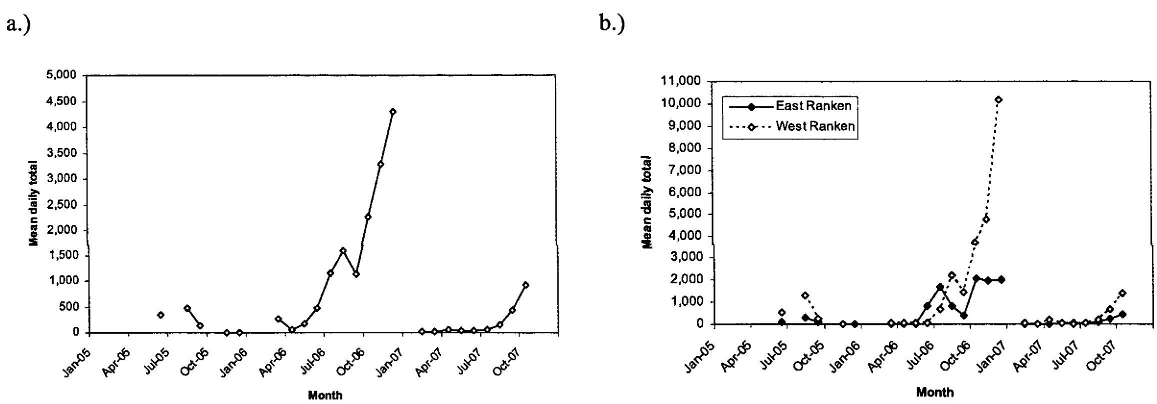

Figure 4 Mean daily total per month of Flock Bronzewing Pigeons at a.) all bores, and b.) bores on separate bore-runs on Alexandria Station from June 2005 to October 2007.

The number of Flock Bronzewing Pigeons recorded on each bore-run, and at individual bores, on a daily basis was highly variable (Figures 5 and 6). There appears to be some evidence of movement of birds from the East Ranken portion in mid 2006, and concentration in the West Ranken portion (Figure 5), but there is no evidence from marked birds to support this suggestion. Movement patterns within and between grasslands habitats are likely to be complex.

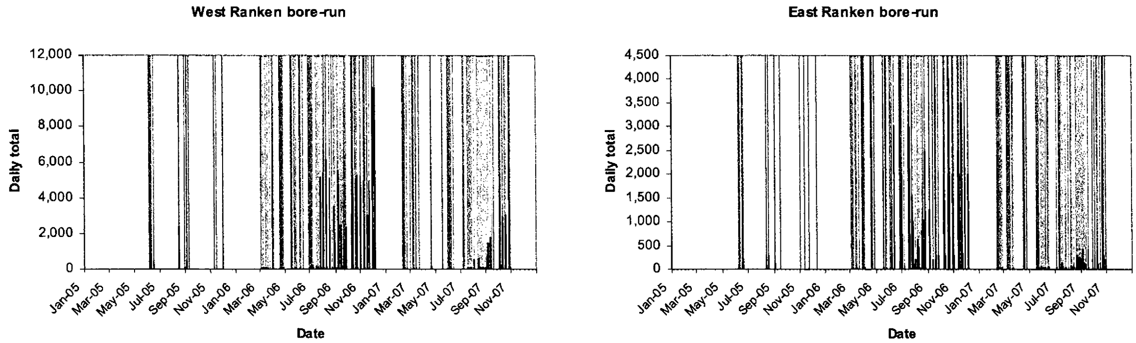

Figure 5 Daily totals of numbers of Flock Bronzewing Pigeons seen at bores on West Ranken bore-run, and East Ranken bore-run, from June 2005 to October 2007. Survey days are shown in grey.

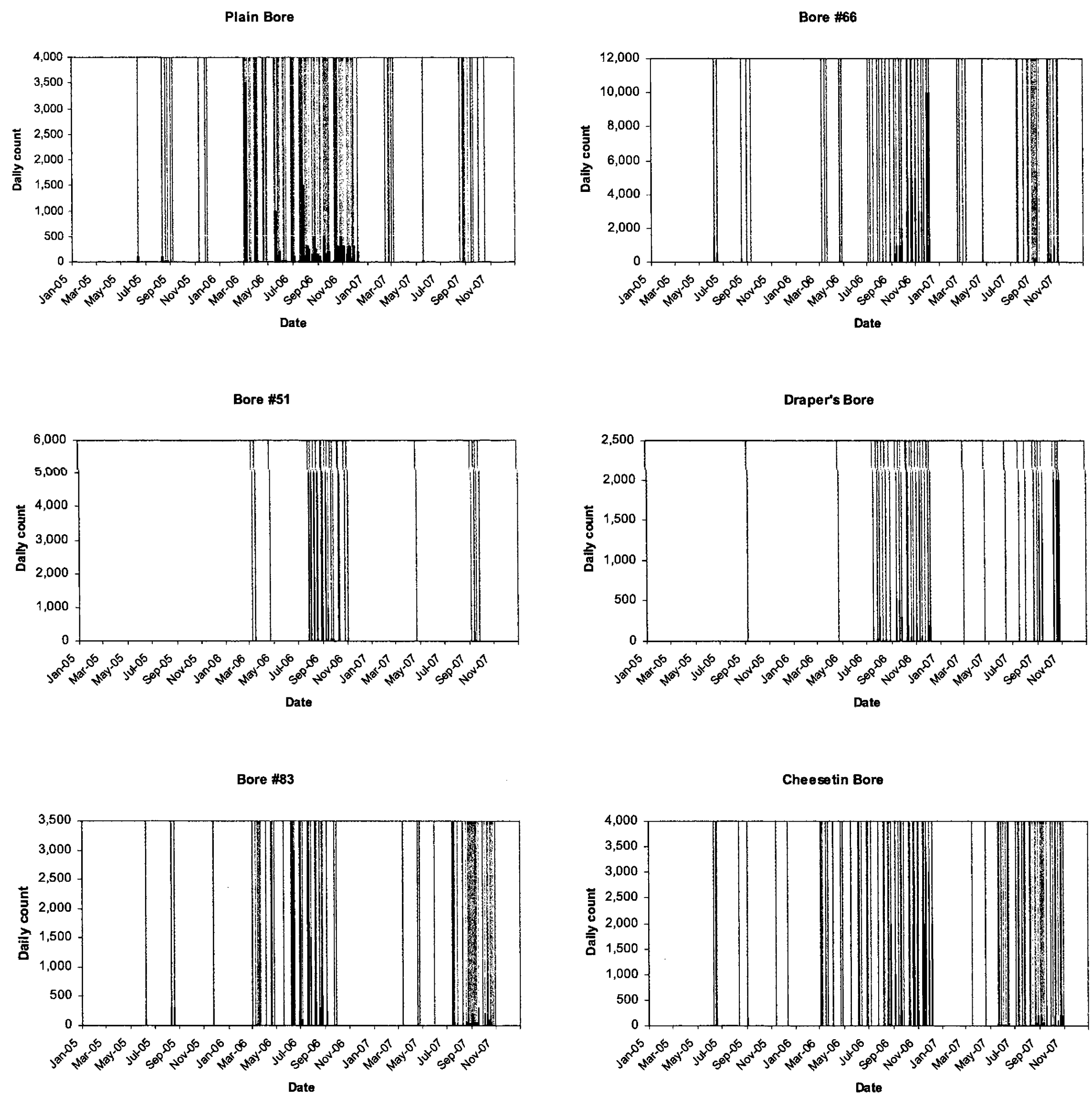

Figure 6 Daily totals of numbers of Flock Bronzewing Pigeons seen at six bores on Alexandria Station, including three on West Ranken bore-run (Bore #66, Bore #51 and Draper's bore) and three on East Ranken bore-run (Plain bore, Bore #83 and Cheesetin bore) from June 2005 to October 2007. Survey days are shown in grey.

Patterns of plant productivity

Minimum convex polygons enclosing the West Ranken and East Ranken bore-runs overlie areas with substantially different spatial patterns of maximum April GPP of raingreen vegetation, with West Ranken covering areas of highest plant productivity associated with the Playford River drainage system in the western half of Alexandria Station (Figure 7). Monthly patterns of GPP of raingreen component of vegetation are similar between bore-runs, with the West Ranken bore-run polygon attaining higher GPP in the wet season in most years (Figure 8).

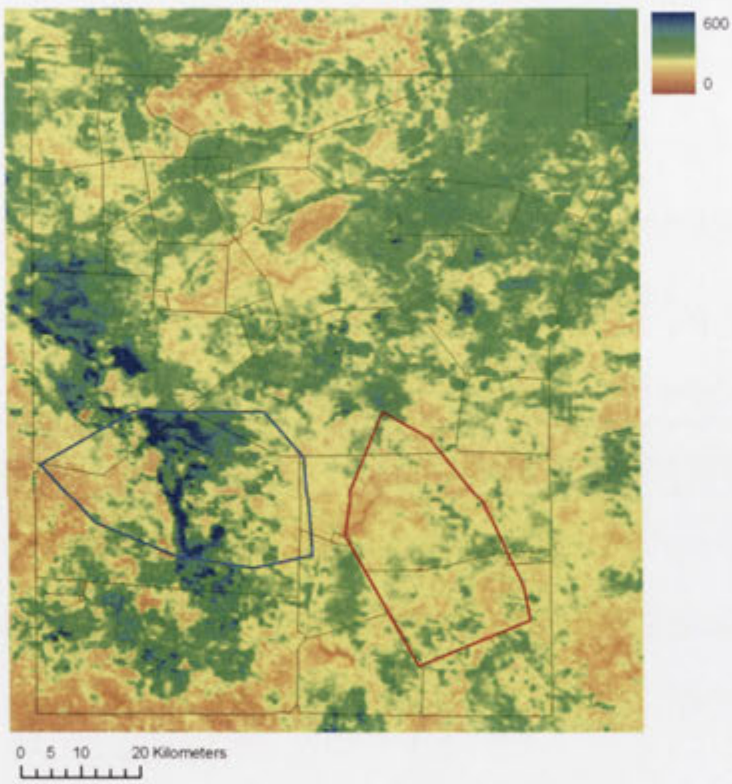

Figure 7 Map of Alexandria Station showing maximum GPP and minimum convex polygons enclosing West Ranken (blue) and East Ranken (red) bore-runs.

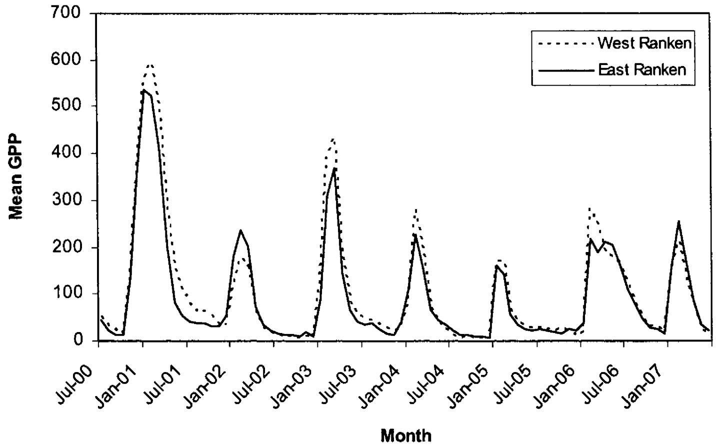

Figure 8 Monthly variation in mean GPP derived from 100 random points within minimum convex polygons enclosing West Ranken and East Ranken bore-runs.

DISCUSSION

At Alexandria Station on the Barkly Tableland Flock Bronzewing Pigeons were found to occur in relatively large numbers in each of three years from 2005 to 2007. The year 2006 was notable due to the above average rainfall, including significant rainfall in the latter half of the wet season following the development of a tropical depression in the wake of cyclone Monica at the end of April. In general, in each year numbers increased throughout the dry season to maxima in the late dry season, and were least in the early dry season. There were no observations during the wet season and it is not known whether birds were present.

The observed intra-annual increase in numbers in 2006 and 2007 may be due to three processes, namely (i) recruitment following successful nesting, (ii) changes in local dispersion of birds throughout the dry season as natural waterbodies dry and birds concentrate on fewer artificial waters, or (iii) by immigration from areas outside the study areas. Almost certainly all three factors are involved. There were signs of active breeding from early 2006, including aerial display flights, though no nests were found. A recently fledged chick was flushed from the grass by a passing vehicle and subsequently attacked by a raptor in late April 2006. Elsewhere in the Barkly on Helen Springs Station nests were found in three occasions and aerial breeding displays were observed throughout the dry season.

The data do not reveal whether birds are present during the wet season. There is a gap in the observations between early December 2006 to early February 2007 during which numbers declined dramatically due to either emigration beyond the study area or region, or to a change in the pattern of dispersion within the study area. Limited data from the tracking of birds tagged with satellite transmitters (Chapter 10) suggest that birds undertake large movements early in the wet season after the first substantial rainfall, a result which is congruent with these studies and supported by observations of pastoralists. In other granivorous birds movements of various scales are triggered by food depletion following seed germination after rainfall (Ward 1971, Dostine *et al.* 2001, Lloyd *et al.* 2001). The extent and direction of early wet season movements of Flock Bronzewing Pigeons remains relatively unexplored, though existing evidence suggests that they are seeking floristically and phenologically distinct patches within the region which provide a different set of resources in the wet season.

Differences in the abundance measures for Flock Bronzewing Pigeons between bore-runs are consistent with differences in the underlying patterns of plant productivity as measured by remote sensing. There were no measures of the availability of preferred habitat or food abundance between bore-runs and consequently the link between abundance and plant productivity remains tentative and speculative.

The regular appearance of numbers of Flock Bronzewing Pigeons at watering points provides an opportunity to assess the size of local populations; there are few available alternative approaches. During the day birds forage on the ground in tussock grassland; their cryptic coloration and habits render them largely undetectable unless flushed by close approach. An approach using repeated visits to known favoured sites, to record both absence and presence, at a standardised time, might form the basis for ongoing long-term monitoring.

SUMMARY OF FINDINGS AND CONCLUSIONS

Data were collected on numbers of Flock Bronzewing Pigeons at pastoral bores in a portion of Alexandria station on the Barkly Tableland on 282 days in a three year period from 2005 to 2007. There were 821 data records of Flock Bronzewing Pigeons at 30 bores, yielding a total count of over 200,000 birds. Most records (88.3%) occurred prior to mid-day, with a peak between 2-2.5 hours after sunrise.

The abundance of Flock Bronzewing Pigeons varied between years in a manner consistent with variation in annual seasonal rainfall: numbers were low in 2005 following the wet season of 2004/05 with percentage rank seasonal rainfall of 29.8%; high in 2006 following the wet season of 2005/06 with percentage rank seasonal rainfall of 90.9%; and low in 2007 following the wet season of 2006/07 with percentage rank seasonal rainfall of 66.1%. Numbers decline markedly from the late dry season to the following early dry season, principally due to emigration initiated by wet season rainfall. The fate of dispersing birds is unknown, and there are no measures of abundance during the wet season.

There were differences in population indices for adjacent blocks on Alexandria station: the reasons for such differences are unclear, but may be associated with spatial patterns of plant productivity.

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Appendix 3: NOTES ON CAPTURE METHODS

INTRODUCTION

Flock Bronzewing Pigeons are particularly cautious, and conventional capture techniques such as mist-netting were found to be inappropriate for this species. Flock Bronzewing Pigeons inhabit extensive open grasslands of the black-soil plains of northern Australia and are most commonly encountered as individuals and small groups aggregate prior to drinking either in the hours following sunrise or prior to sunset. Drinking occurs either at the periphery of natural or artificial water-bodies, or whilst briefly alighted on the water surface. In rangeland country in northern Australia the species commonly drinks at small dams filled with artesian water for watering stock known as 'turkey-nest dams'. Birds tend to gather some distance from water in the vicinity of turkey-nest dams, and prior to drinking fly in a tightly coordinated flock, circling the dam many times before landing elsewhere without drinking. This sequence may be repeated several times before landing to drink. Their nervous and flighty disposition, and avoidance of nets and other trapping hardware poses a considerable challenge for researchers aiming to tag or sample individuals of this species for ecological study. The species is recorded in the Australian Bird and Bat Banding Scheme database on one occasion only after birds were serendipitously flushed into mist nets set for studies of another species. The method described here draws its inspiration from bushcraft skills displayed by the early explorers. Daniel Brock, the preparator on Charles Sturt's expedition into central Australia of 1844-46, describes an attempt to ensnare pigeons with horsehair nooses.

> The first thing we did was to light a fire and get some refreshment, after which we very carefully laid our snares for the pidgeons which were long to come – night drew on, yet not a rascal has shewed its feather (Peake-Jones 1975, cited in McAllan 1996).

METHODS

There were several failed attempts over an 18 month period to develop a successful capture method, including trials of various forms of net traps, and attractants such as decoys and seed beds (Figures 1 and 2). Mist nets are particularly unsuitable in such open environments: they are highly visible and are easily avoided, and are affected by the prevalent south-easterly winds on the Barkly throughout dry season months. Painted decoys made of polyurethane foam, and seed beds, were ignored. Flock Bronzewing Pigeons are extremely wary of human presence and avoid trapping paraphernalia.

A trapping method using leg-nooses was successfully developed and applied to capture of Flock Bronzewing Pigeons. Traps consisted of nooses attached to rubber strips pegged to the ground and positioned to intercept birds as they walk to the edge of the dam to drink or as they walk around the periphery of the dam (Figure 3). Rubber strips were rectangular in cross-section (8.3 x 3.3 mm). Traps measured about 70 cm in length (mean 701 ± 3.3 mm, n=16), and held about 17 individual nooses (range 16-19, median 17, n=16) at an interval of 4 cm. Nooses were constructed of 6 kg clear monofilament nylon fishing line and were constructed using the running slip-knot described by Jenkins (1979) for raptor traps. Sections of monofilament line cut to 20-22 cm lengths were attached to the rubber strip by tying one end of a length of monofilament to a 2.5 mm plastic craft bead using the same running slip-knot and threading the monofilament through the rubber strip with a heavy sewing needle and secured by gluing the bead to the rubber strip with super-glue. Nooses were tied on the free end of the monofilament line. Each end of the trap held a short length of 8 kg monofilament line held using the same method and attached to a small brass ring (external diameter 6.8 mm, internal diameter 4.2 mm) connected to a rubber band. Traps were held on the ground by light-weight tent pegs at either end, and in the middle. The elasticity of the rubber strip and elastic bands minimises the risk of injury whilst in the trap. Traps were placed in shallow trenches and covered with soil so that only the nylon loops were visible.

Traps were deployed after observation of the behaviour of the birds as they approached the water to drink to maximise the probability of interception and capture. The number of traps deployed was adjusted to lower the risk of capturing more than a few birds. Traps were placed at sufficient distance from the edge to avoid the risk of captured birds contacting wet mud or water. Traps need to be within clear view for rapid removal of captured birds. On capture birds were covered by cloth bags which were subsequently inverted over the birds; all subsequent handling was conducted with the head being covered.

Figure 1 Remains of a painted decoy after vigorous attack by a crow at a stock-bore on Brunette Downs Station.

Figure 2 Setting a flip-trap with seed bed at a stock-bore on Brunette Downs Station.

RESULTS AND DISCUSSION

This method was used to capture 75 individuals after initial success on 14th June 2006. One Flock Bronzewing Pigeon landed on the surface of the dam after being poorly held by a trap; this individual was recovered by swimming and held overnight and was successfully released the following morning. A mortality directly attributable to the trapping method occurred when two individuals caught in near adjacent nooses of the same trap tangled, leading to asphyxiation and death of one of the captured birds. By-catch species included individual Magpie Lark *Grallina cyanoleuca*, Galah *Eolophus roseicapillus*, Australian Pratincole *Stiltia isabella* and Banded Lapwing *Vanellus tricolor*. All were released unharmed.

Figure 3 Trapping site at bore 9, Glenroy paddock, Helen Springs Station.

Several noose traps are positioned along the dam wall to intercept birds as they approach the water to drink after landing on the dam wall.

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Appendix 4: SUMMARY OF COMMENTS FROM LANDHOLDER SURVEYS IN 2002/03 AND 2005

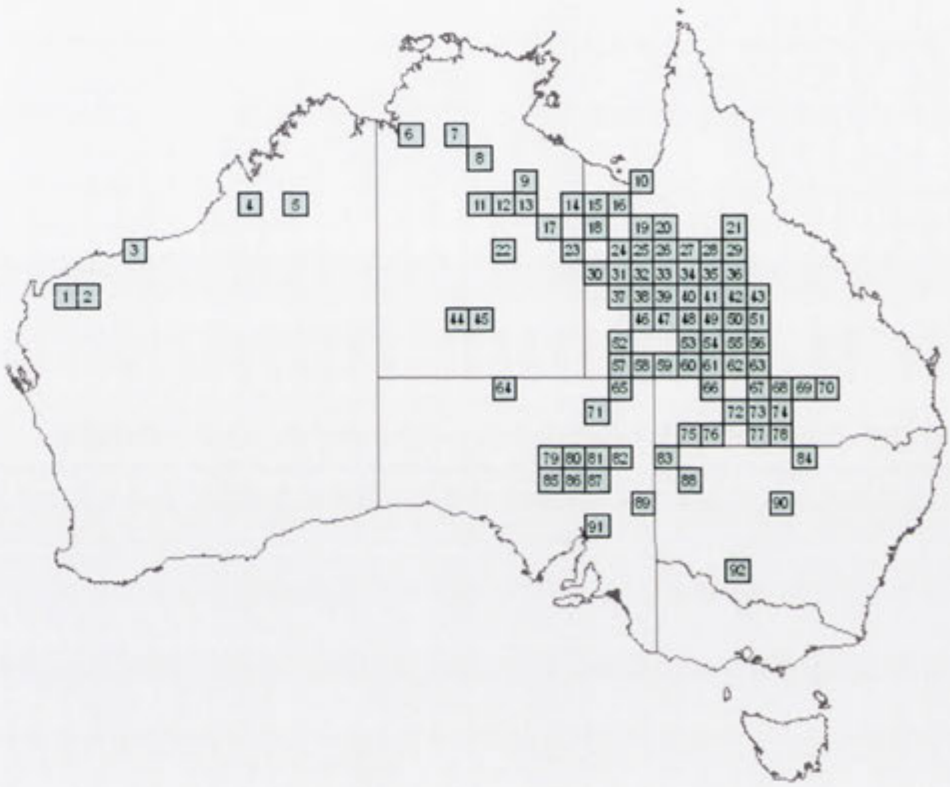

Figure 1 Map showing location of cell numbers referred to in Tables 1-3.

Table 1 Favourable years identified by respondents to mail-out surveys conducted in 2002/03 and 2005.

Cellno	State	Midlat	Midlong	Property	Survey	Favourable years
6	NT	-15.5	130.5	Auvergne	2005	1970s
8	NT	-16.5	133.5	Hayfield	2005	10 years ago (early-mid 1990s)
16	Qld	-18.5	139.5	Brinawa	2005	Not seen for at least 20 years
16	Qld	-18.5	139.5	Floraville	2002	Early 1970s
16	Qld	-18.5	139.5	Floraville	2005	1970-74
18	Qld	-19.5	138.5	Elsewhere	2002	Declined from 1947-50
19	Qld	-19.5	140.5	Brinard	2005	Early 1990s
21	Qld	-19.5	144.5	Werrington	2002	Barkly 1960s and 1970s
25	Qld	-20.5	140.5	Gipsy Plains	2005	30 years since big numbers (1970s)
26	Qld	-20.5	141.5	Ernestina Plains	2002	Once in 1991
26	Qld	-20.5	141.5	Zonia Downs	2002	1974
27	Qld	-20.5	142.5	Proa	2005	Early 1960s
28	Qld	-20.5	143.5	Rokeby	2005	1954-55, 1996-97
29	Qld	-20.5	144.5	Delbessie	2002	10 years ago (early-mid 1990s), once in 30years
29	Qld	-20.5	144.5	Torver Valley	2002	1985-88
32	Qld	-21.5	140.5	Maronan	2002	1972-75
33	Qld	-21.5	141.5	Bull Creek	2002	1990s
33	Qld	-21.5	141.5	Bull Creek	2002	1971
36	Qld	-21.5	144.5	Strathroy	2005	Once, about 20 years ago.
36	Qld	-21.5	144.5	Thornville	2002	Late 1950s, early 1960s
36	Qld	-21.5	144.5	Thornville	2002	1955-63
41	Qld	-22.5	143.5	Belmont	2005	Late 1960s, early 1970s
41	Qld	-22.5	143.5	Cronulla	2002	Early 1960s
42	Qld	-22.5	144.5	Maylands	2005	1954-56, 1974-75
42	Qld	-22.5	144.5	Weewondilla	2002	1964
42	Qld	-22.5	144.5	Weewondilla	2005	1963-64
43	Qld	-22.5	145.5	Ballygar	2002	1994
49	Qld	-23.5	143.5	Mount Victoria	2002	1967, 1968, 1989, 1990
49	Qld	-23.5	143.5	Westfield	2002	1920, 1921
50	Qld	-23.5	144.5	Fairfield	2002	Many 30 years ago (1970s)
51	Qld	-23.5	145.5	Willoughby	2005	1950-56
54	Qld	-24.5	143.5	Lochern NP	2005	1993-94
65	SA	-26.5	139.5	Pandie Pandie	2005	1970s
66	Qld	-26.5	143.5	Berellam	2002	1990
69	Qld	-26.5	147.5	Cotswold	2002	1970s, 1990s
71	SA	-27.5	138.5	Cowarie	2002	1992
74	Qld	-27.5	146.5	Whitewater	2002	1974
78	Qld	-28.5	146.5	Donna Downs	2002	1988, 1989
81	SA	-29.5	138.5	Clayton	2005	1950, 1955, 1974, 1976
82	SA	-29.5	139.5	Woolatchi	2002	1974, 1976
89	SA	-31.5	140.5	Mooleulooloo	2002	1955, 1956, 1968
92	NSW	-34.5	144.5	One Tree	2002	1988
				Prop 15	2005	1974-75
				Prop 359	2005	1956-59, 1974-75

Table 2 Comments received from respondents to both mail-out surveys indicating presence of large aggregations of Flock Bronzewing Pigeons.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
16	Qld	-18.5	139.5	Floraville	2002	Flocks of 10,000s in early 70s, covered 3 km^2 of ground.
16	Qld	-18.5	139.5	Floraville	2005	In the early 70s there were hundreds of thousands of these birds (flocks spread over 5 km range on ground). This coincided with very dry conditions in south-west Queensland and very good seasons here. Prolific 1970-1974, nest with eggs can't recall what month.
18	Qld	-19.5	138.5	Elsewhere	2002	Flock Pigeons have diminished drastically since 1947-50. Along Georgina River plains used to be in 10,000s.
19	Qld	-19.5	140.5	Brinard	2002	When last here they were in the 1,000's and moved on.
19	Qld	-19.5	140.5	Brinard	2005	In the early nineties - can't remember exactly - an enormous flock of absolutely 1000s of birds came here and were around the homestead for a few weeks, then moved on - have never seen them like that before or since. Sheep ceased 4 years ago.
25	Qld	-20.5	140.5	Gipsy Plains	2002	Have seen huge flocks of them on occasion.
25	Qld	-20.5	140.5	Gipsy Plains	2005	I have always noticed them but never noted a particular date or year. 30 odd years since I have seen big numbers of them. 500+ in flocks.
26	Qld	-20.5	141.5	Carrum	2005	They seem to appear in good seasons when the Mitchell grass is good and can be seen in large mobs 1,000s.
27	Qld	-20.5	142.5	Proa	2005	We have controlled the feral animals over the past 20 years. Early 60's Flock Pigeons were at Proa in their thousands.
28	Qld	-20.5	143.5	Rokeby	2005	Been in this area since 1952. In 1954-1955 on downs country, Afton Downs property, Flock Pigeons in big flocks. In 1996-1997 at our property, Rokeby, here in thousands all in different flocks landing at dam.
29	Qld	-20.5	144.5	Gunnerside	2005	Very large flocks (1,000 or more birds in flock) but only after very good above average rain and wet season. Nomadic, do not breed in area.
29	Qld	-20.5	144.5	Torver Valley	2002	Between 1985-1988 flocks used to block out sunlight and cover 50% of stored water facility.
36	Qld	-21.5	144.5	Thornville	2002	Many very large flocks (1000's) in late 50s, early 60s.
42	Qld	-22.5	144.5	Warrandaroo	2005	It is very unusual for them to be around now but owing to out of season winter rain they are here. Seasonal - after good rains. Owing to out of season rain (in winter) there is a large flock (500-1,000) waiting on dam. They are always here after good rain.
53	Qld	-24.5	142.5	Eldwick	2005	At present there are thousands of pigeons on dam bands etc.
54	Qld	-24.5	143.5	Juno Downs	2005	Open downs country, coming to water pm, biggest flock approx 3,000 (8/12/05 am). Following good rainfall.
81	SA	-29.5	138.5	Clayton	2005	In 1950, 1955, 1974 & 1976 they bred in thousands.
81	SA	-29.5	138.5	Dulkaninna	2005	Flock Pigeons move about with the seasons. They are always plentiful on Clifton Hills Station. Have seen them in the thousands.
81	SA	-29.5	138.5	Dulkaninna	2002	Always see a few each year; this year best for a long time.

Table 3 Summary of general comments received from respondents to both mail-out surveys.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
2	WA	-22.5	116.5	Kooline	2005	Few large flocks (200-300 birds). Come and go with good and bad seasons (haven't seen them for five years).
3	WA	-20.5	118.5	Indee	2005	Occasionally I see 2 or 3 birds. It is spinifex country but I do not see them near water.
3	WA	-20.5	118.5	Wallareenya	2005	Never taken any notice of when, how many, since you asked have taken note. Six this week all on last years burns.
4	WA	-18.5	123.5	Dampier Downs	2002	Near last waters late in season.
5	WA	-18.5	125.5	Jubilee Downs	2002	Don't see many prior to the wet; always get them on the BSOP, they nest in Mitchell and Flinders grass. See them when mustering.
5	WA	-18.5	125.5	Jubilee Downs	2005	They are always seen on the Mitchell & Flinders grass blacksoil plains.
6	NT	-15.5	130.5	Auvergne	2005	In one area there has been an increase in number. Perhaps woody weed encroachment has an influence. Dingoes and Flock Pigeons were in large numbers 1970s. Cats could be the main problem.
8	NT	-16.5	133.5	Hayfield	2005	Can remember seeing huge clouds of them 10 years ago. They came and went in a couple of months. Haven't seen them in those numbers again.
8	NT	-16.5	133.5	Sunday Creek	2002	Rare visitors, either singly or small numbers.
16	Qld	-18.5	139.5	Brinawa	2005	Have not noticed these birds for at least 20 years mainly in the years with the best floods.
16	Qld	-18.5	139.5	Floraville	2002	Flocks of 10,000's in early 70s, covered 3 km^2 of ground.
16	Qld	-18.5	139.5	Floraville	2005	In the early 70s there were hundreds of thousands of these birds (flocks spread over 5 km range on ground). This coincided with very dry conditions in south-west Queensland and very good seasons here. Prolific 1970-1974, nest with eggs can't recall what month.
16	Qld	-18.5	139.5	Wernadinga	2002	See them at different times but mainly in drought years to the south.
18	Qld	-19.5	138.5	Elsewhere	2002	Flock Pigeons have diminished drastically since 1947-50. Along Georgina River plains used to be in 10,000s.
19	Qld	-19.5	140.5	Brinard	2002	When last here they were in the 1,000s and moved on.
19	Qld	-19.5	140.5	Brinard	2005	In the early nineties - can't remember exactly - an enormous flock of absolutely 1000s of birds came here and were around the homestead for a few weeks, then moved on - have never seen them like that before or since. Sheep ceased 4 years ago.
19	Qld	-19.5	140.5	Gleeson	2002	Tend to stick to open black soil Mitchell grass country around water.
20	Qld	-19.5	141.5	Balootha	2005	Flock Pigeon only seem to breed in our area in big seasons but are seen on other occasions.
20	Qld	-19.5	141.5	Bow Park	2002	While seed is plentiful.
21	Qld	-19.5	144.5	Werrington	2002	Huge flocks in the Barkly in 60s and 70s.
25	Qld	-20.5	140.5	Gipsy Plains	2002	Have seen huge flocks of them on occasion.

Table 3 cont.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
25	Qld	-20.5	140.5	Gipsy Plains	2005	I have always noticed them but never noted a particular date or year. 30 odd years since I have seen big numbers of them. 500+ in flocks.
25	Qld	-20.5	140.5	Oorindi Park	2002	Stay 2-3 months sometimes longer; good numbers when lot of seed after rain. None during drought.
26	Qld	-20.5	141.5	Carrum	2005	They seem to appear in good seasons when the Mitchell grass is good and can be seen in large mobs 1,000s.
26	Qld	-20.5	141.5	Ernestina Plains	2002	Only seen about 10 pigeons once in 1991; not prevalent around here.
26	Qld	-20.5	141.5	Lindfield	2005	We often get Flock Pigeons but when in big numbers never seen eggs. Very rarely ever see eggs "but they are hard to find".
26	Qld	-20.5	141.5	Zonia Downs	2002	No bronzewings around at the moment due to drought, need a good wet to see them.
27	Qld	-20.5	142.5	Bundoran	2002	Only time I've seen very large flocks is after a good wet season, when dry elsewhere.
27	Qld	-20.5	142.5	Edith Downs	2002	Neighbour saw large flocks last year.
27	Qld	-20.5	142.5	Proa	2005	We have controlled the feral animals over the past 20 years. Early 60s Flock Pigeons were at Proa in their thousands.
27	Qld	-20.5	142.5	Trivalore	2002	Gradual increase last 12 years, in 1997 light season but good flocks of 50, we're at western edge of FB range & eastern of squatter, both have increased in winter.
28	Qld	-20.5	143.5	Dunluce	2005	Very intermittent sightings over the years.
28	Qld	-20.5	143.5	Rokeby	2005	Been in this area since 1952. In 1954-1955 on downs country, Afton Downs property, Flock Pigeons in big flocks. In 1996-1997 at our property, Rokeby, here in thousands all in different flocks landing at dam.
29	Qld	-20.5	144.5	Delbessie	2002	Only once in 30 years have Flock Pigeons been here about 10 years ago.
29	Qld	-20.5	144.5	Gunnerside	2005	Very large flocks (1,000 or more birds in flock) but only after very good above average rain and wet season. Nomadic, do not breed in area.
29	Qld	-20.5	144.5	Torver Valley	2002	Between 1985-1988 flocks used to block out sunlight and cover 50% of stored water facility.
32	Qld	-21.5	140.5	Maronan	2002	Flock Pigeons are nomadic, there were above average rainfalls in mid-1970s and flocks of several hundred birds were seen.
33	Qld	-21.5	141.5	Bull Creek	2002	North of Julia Creek in the Downs country in the 1990s there were big flocks.
33	Qld	-21.5	141.5	Delacourt	2002	In some good seasons with abundance of Flinders grass may stay all year.
33	Qld	-21.5	141.5	Delacourt	2005	Drought years - no pasture - no seed - no birds.
33	Qld	-21.5	141.5	Kenellen	2005	Flock Pigeons can usually be observed at dusk, year round, coming to water at Kenellen, though in quite small numbers during very dry spells. On our other properties near Cloncurry, north-west Queensland, Flock Pigeons are present during and after better than average seasons, but scarce during dry spells. Common Bronzewings are abundant in the Cloncurry area. Better than usual grass cover, prolonged wet season.

Table 3 cont.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
34	Qld	-21.5	142.5	Maroola	2005	Predators in low numbers . . . because we 1080 bait. They are here every year.
34	Qld	-21.5	142.5	Nuken	2002	Only ever see them after rains and then only a few.
34	Qld	-21.5	142.5	Nuken	2005	Numbers have not changed in this area in 30 yrs.
35	Qld	-21.5	143.5	Conamore	2005	Have seen 1 mob of about 12 birds end November 2005. Perhaps passing through.
35	Qld	-21.5	143.5	Eldorado	2005	After summer rain.
35	Qld	-21.5	143.5	Hazelwood	2002	Have seen large numbers south of Richmond, Queensland. I am north and only see a few.
35	Qld	-21.5	143.5	Katandra	2002	Not in big flocks. Some only, number half dozen, while largest flock I saw last year equals 30.
35	Qld	-21.5	143.5	Wyora	2002	Haven't seen any for a few years; kept one as a pet.
36	Qld	-21.5	144.5	Hillview	2005	We don't have many Flock Pigeons here. I would regard them as rare here.
36	Qld	-21.5	144.5	Strathroy	2005	Only ever seen here in big numbers the once - approx 20 years ago - assume because grass here at the time and nil elsewhere.
36	Qld	-21.5	144.5	Thornville	2002	Many very large flocks (1000s) in late 50s, early 60s.
36	Qld	-21.5	144.5	Zara	2002	Only seen a few times.
38	Qld	-22.5	140.5	Slashers Creek	2005	Could be same mob sighted several times.
39	Qld	-22.5	141.5	Mackunda	2005	Flock Pigeons are not as common here as the Corfield area. I have no record of seeing them in 2004.
40	Qld	-22.5	142.5	Elderslie	2005	Flock Pigeons are only seen every 8-10 years - not here on a regular basis. When here are sighted mostly on waters (open dams), else feeding on the ground not far from water. Only seen on downs country. Never in channels or hilly areas.
40	Qld	-22.5	142.5	The Grove	2005	The Flock Pigeons I have seen have been in small numbers.
41	Qld	-22.5	143.5	Baratria	2005	Seen 3 times in flock of 300-400.
41	Qld	-22.5	143.5	Belmont	2005	Flock Pigeons were very abundant in the late 60s-early 70s. They disappeared for years and only appeared in odd small amounts in the late 70s-80s and 90s. They were fairly abundant a year or two ago (unsure of which year it was). Unsure (of best years) late 1960s and early 2000s to 2005 best times. There were a fair few nesting in the time between 2000 and 2005. Can't remember which year but. Nesting in August I think!
41	Qld	-22.5	143.5	Camara_1	2005	Good winter rain.
41	Qld	-22.5	143.5	Cronulla	2002	Big flocks in early 60s, maximum now 30.
41	Qld	-22.5	143.5	Cronulla	2005	My comments cover over 4 places Cronulla, Longreach; Maranthorne, Muttaburra; Congewoi, Kynuna; Marchmont, Ilfracombe one large flock 160+.
41	Qld	-22.5	143.5	Daintree	2002	Stay 4-5 months; seen here in response to good seasons and abundant grass; near waterholes dams.
41	Qld	-22.5	143.5	Daintree	2005	1974 and 2000 were both very big years for rain & pasture, yet I don't recall them being exceptional for numbers of pigeons.

Table 3 cont.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
41	Qld	-22.5	143.5	Eyriewald	2002	Only get large flocks (100) about every 10 years, most years see 2-6 occasionally after first late summer storms. Onlycome in good years and possibly when dry north-west of here.
41	Qld	-22.5	143.5	Eyriewald	2005	Back in the early fifties was the first time I really noticed flock pigeons. There were big flocks at times. They have been less mobs the last 10 years. Two years ago there were a few mobs about of about 200. Just about every year odd pairs appear once the summer rains are over. They seem to settle in pairs in the open downs country between April May June and at times have noted egg and young. Probably not many succeed.
41	Qld	-22.5	143.5	Llewellyn	2005	We only get them in season. In good seasons.
41	Qld	-22.5	143.5	Marita Downs	2005	In good seasons when there is abundant grass cover for nesting, pigeons are prolific in numbers.
42	Qld	-22.5	144.5	Camara_2	2005	There are very few sightings of pigeons in this area. A maximum of 4 for very short time.
42	Qld	-22.5	144.5	Kensington Downs	2002	We see bronzewings very occasionally here, but I here others speak of them in the general area so they are about.
42	Qld	-22.5	144.5	Maroomba	2002	This last year has been in drought (therefore the low Flock Pigeon numbers).
42	Qld	-22.5	144.5	Maylands	2005	A lot of droughted areas around here so would not expect any in near future. Top-knot pigeons are always in this area. 1954-55-56 and 1974-75, I am retired but it was only in unusually good sequences of seasons that pigeons were observed.
42	Qld	-22.5	144.5	Warrandaroo	2005	It is very unusual for them to be around now but owing to amount of season winter rain they are here. Seasonal - after good rains. Owing to out of season rain (in winter) there is a large flock (500-1000) waiting on dam. They are always here after good rain.
42	Qld	-22.5	144.5	Weewondilla	2005	Prior to 1972 I lived west of Jundah and observed large flocks in good seasons of 1963-64. My only sightings since (either there or here) have been small. My range of observation is 200 km south of Longreach to 200 km south of Longreach.
43	Qld	-22.5	145.5	Ballygar	2002	In 1994 very large numbers on one of our other properties.
44	NT	-23.5	132.5	Narwietooma	2002	Sporadic.
45	NT	-23.5	133.5	Amburla	2005	Suggest Alice Springs area. When stock are high in Barkly area. Downs country.
46	Qld	-23.5	140.5	Lorna Downs	2005	It's been a very dry few years. I watch the birds all the time and was very excited when I saw these ones. They were not scared of me and kept landing if too close and re-flying above in same area. Very large flock 100-130 saw a few days ago, have never seen before, waterhole near house.
47	Qld	-23.5	141.5	Brighton Downs	2005	Only started making notes on Flock Pigeon sightings on 30/10/05.
48	Qld	-23.5	142.5	Weona	2005	Rainfall above average but not widespread over property, foxes absent due to regular 1080 baitings.
49	Qld	-23.5	143.5	Dalkeith	2005	Interest in Flock Pigeons has only arisen in the last few years. Estimates of numbers and seasonal comings and goings in the decades prior to this is virtually nil.

Table 3 cont.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
49	Qld	-23.5	143.5	Euston	2005	When watering they line up and come down to water in line 4-6 abreast, no one breaks ranks.
49	Qld	-23.5	143.5	Marmboo	2002	Only seen when grass is green after rain.
49	Qld	-23.5	143.5	Marmboo	2005	Have seen 1 Bronzewing this year. Crested and Spinifex Pigeons are abundant after good wet season.
49	Qld	-23.5	143.5	Mount Ryde	2005	In my time the numbers are static, just the odd few in some years. I've never seen more than a dozen in a flock. Always sparse numbers and only if there has been a season.
49	Qld	-23.5	143.5	Mount Victoria	2005	We used to see small flocks down to singles. None seen for many years.
49	Qld	-23.5	143.5	Mt Ryde	2002	The few times they've been here they stay only 1 week, they are very rare here. Since 1970 in Longreach area I have only seen them 10 times for total of 50-60 birds.
49	Qld	-23.5	143.5	Westfield	2002	Seldom seen.
50	Qld	-23.5	144.5	Dundonald	2005	Only see Flock Pigeons and bustards in good seasons. Can't put actual years but always see them in good season.
50	Qld	-23.5	144.5	Fairfield	2002	Many 30 years ago, none around for years; affected by fox and cats.
50	Qld	-23.5	144.5	RodneyDowns	2005	Did see them in mobs of 20-30 with mobs of cockatiel last two months of last year. I found that a bit unusual. They are mainly seen on the open downs country not in the creek channels - along the bore drains mainly. Flocks up to 200.
51	Qld	-23.5	145.5	Orange Downs	2005	This property is open Mitchell and Flinders grass black soil downs (savannah grassland).
51	Qld	-23.5	145.5	Willoughby	2005	There were frequent sightings of Flock Pigeons in our high rainfall years of 1950 to 1956 they have been virtually absent since. In Feb 2007 I saw a flock of 6 birds on a forested property 100 kms north north-east of our property which is on open Mitchell grass downs country.
53	Qld	-24.5	142.5	Eldwick	2005	At present there are thousands of pigeons on dam bands etc.
54	Qld	-24.5	143.5	Boree Downs	2002	Seem shy and don't seem to manage when grass is shorter and foxes/cats in any numbers.
54	Qld	-24.5	143.5	Boree Downs	2005	Flock Pigeons appear west of this property on the open downs band on the eastern side of the Thompson River.
54	Qld	-24.5	143.5	Elward Downs	2005	Only a couple of sightings in the last few months - 300 on a dam bank only a few days ago. Very droughted here but good Mitchell only kms away at Bimerah so should be plenty of seed. Two other neighbours only cattle and lightly stocked so plenty of seed there. My sub-conscience tells me they're associated with wet seasons - maybe still to come!!
54	Qld	-24.5	143.5	Glen Valley	2005	Seen most of the year.
54	Qld	-24.5	143.5	Isla Downs	2005	The Flock Pigeons when seen are very distinct from the Crested and Spinifex pigeons we also have. We have been droughted out last 4 years.
54	Qld	-24.5	143.5	Juno Downs	2005	Open downs country, coming to water pm, biggest flock approx 3000 (8/12/05 am). Following good rainfall.
54	Qld	-24.5	143.5	Kaloola	2002	Green season at present and have seen 2 in one day, sometimes go for 6 months without seeing any.

Table 3 cont.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
54	Qld	-24.5	143.5	Laidlaw	2005	We have shot a lot of feral cats over the past year but we always see a few Bronzewings around the property, perhaps not as many during the last 4 years.
54	Qld	-24.5	143.5	Lochern NP	2005	Neighbour Angus Emmott told me he has seen large flocks on Lochern in the past. From the end of 1993 through 1994 I saw large flocks between Longreach and Winton and north of Winton.
54	Qld	-24.5	143.5	Noonbah	2002	Around while good Mitchell grass, anecdotal accounts of large numbers nesting on Warbreccan Stn in early 1900s
55	Qld	-24.5	144.5	Gydia Park	2002	Sightings very brief, only ever see 1-5 birds very infrequently.
59	Qld	-25.5	141.5	Currawilla	2005	I saw a very small flock of 6 pigeons in June. We had 70mm rain. Have not seen since. I was always led to believe by my father and people of the older generation, Flock Pigeons in numbers was a sign of good seasons which I have experienced to be reasonable true.
62	Qld	-25.5	144.5	Milo	2002	Have only seen 1-2 in ten years.
63	Qld	-25.5	145.5	Lambert	2005	Had them once. Due to early rain and plenty of grass seed. Storms very narrow that year, or they were lost. Only time I have seen them.
65	SA	-26.5	139.5	Pandie Pandie	2002	See them now and again in good numbers.
65	SA	-26.5	139.5	PandiePandie	2005	In good seasons and after floods, good floods in 70s.
66	Qld	-26.5	143.5	Berellam	2002	Good conditions not just good rains. First time I saw them in flock of 20 in about 1990, remember it because took me a while to identify them.
66	Qld	-26.5	143.5	Whynot	2005	The lack of Flock Pigeons and turkeys is probably because we have had no summer rain and therefore no grass and seed. Winter rain grows herbage only.
67	Qld	-26.5	145.5	Ravenscourt	2002	Only saw these after good rains in February this year, have never seen them before as your picture.
69	Qld	-26.5	147.5	Cotswold	2002	Large numbers in 1970s smaller flocks in 1990s after good seasons. Rainfall below average b/w 2001-2003 and no birds seen in the area.
71	SA	-27.5	138.5	Cowarie	2002	October 1992 200+ Flock Pigeons in single flock.
76	Qld	-28.5	143.5	Wathopa	2005	We mainly see Top-knots and Bronzewing pigeons. Top notch pigeons come in good years and we don't have many of those probably every 10 years.
77	Qld	-28.5	145.5	Abbadoah	2005	I haven't been paying too much attention to this species to make worthy assessments. But you do notice them and they certainly aren't about as they used to be.
77	Qld	-28.5	145.5	Kywong	2002	There are many cats and foxes here, drought bringing them out so a big eradication program is underway.
77	Qld	-28.5	145.5	Kywong	2005	Most lands in this area have been seriously mismanaged because of people's financial position and there is not much ground cover. I have been destocked since 2001 and am struggling to have grass grow. The birds will only come if there is food and cover.
77	Qld	-28.5	145.5	Thurulgoona	2005	Only occasional.

Table 3 cont.

Cellno	State	Midlat	Midlong	Property	Survey	Comments
78	Qld	-28.5	146.5	Talbalba	2002	A good year in the 1980s?
79	SA	-29.5	136.5	Billa Kalina	2002	Only been seen here in one very good season, a flock of 40.
79	SA	-29.5	136.5	Billa Kalina	2005	I disturbed a nest out on open gibber tableland with 2 chicks recently hatched. A flock of about 50-100 birds were in the area.
80	SA	-29.5	137.5	Muloorina	2002	Good to see them.
81	SA	-29.5	138.5	Clayton	2005	In 1950, 1955, 1974 and 1976 they bred in thousands.
81	SA	-29.5	138.5	Dulkaninna	2005	Flock Pigeons move about with the seasons. They are always plentiful on Clifton Hills Station. Have seen them in the thousands.
81	SA	-29.5	138.5	Dulkaninna	2002	Always see a few each year; this year best for a long time.
82	SA	-29.5	139.5	Moolawatana	2005	Due to drought unlikely to see any until drought breaks. Can't remember - think it was 2002 after summer storms approx March -June.
83	SA	-29.5	141.5	Lindon	2005	Dry times have impacted on all bird life. Bronzewing is more commonly seen 160 kms west of Lindon house (Whitecatch) - Tinga Tingaron is closer to the area. Moomba is a better area again.
87	SA	-30.5	138.5	Farina	2005	After good rains pigeons are spotted in floodout country.
88	NSW	-30.5	142.5	Morden	2005	Main pigeons here are Crested which are thick and a small number of Bronzewings.
90	NSW	-31.5	146.5	Wilgadale	2002	Mix with other pigeons and only in open grassland.
92	NSW	-34.5	144.5	One Tree	2002	Big numbers in 1988; have not seen them in big numbers since.
				Prop 141	2005	Harbinger of rain.
				Prop 15	2005	Flock Pigeons were in tens of thousands in the Barkly Tableland area of NT in 1974-75 seasons as they were very wet years.
				Prop 359	2005	They are cyclic. Were in huge flocks Julia Creek, Richmond areas 1956-1959, 1974-75.