The Effect of Fire on the Breeding Ecology of the Grey-crowned Babbler (Pomatostomus temporalis) in the Australian Monsoon Tropics.

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I hereby declare that the work herein, now submitted as a thesis for the degree of Master by Research at the Charles Darwin University, is the result of my own investigations, and all references to ideas and work of other researchers have been specifically acknowledged. I hereby certify that the work embodied in this thesis has not already been accepted in substance for any degree, and is not being currently submitted in candidature for any other degree.

Signed:

Sarah Fischer
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The Grey-crowned Babbler, *Pomatostomus temporalis*, is a medium-sized sedentary bird that lives in groups of three to eight individuals and breeds cooperatively. In the southern states of Australia it is threatened, mostly by habitat fragmentation. Although the species is still common and widespread in northern Australia, only one study prior to this has focussed on their breeding biology in this part of Australia. As the savannas that dominate the vegetative landscape of the Northern Territory are prone to frequent fire during the dry season (May to October), it is reasonable to suggest that fire has some impact on the reproductive biology of Babblers.

Analysis of breeding data gathered at Coomalie Farm, Northern Territory covering five years, combined with satellite imagery and spatial data revealed that breeding success of the Babbler groups was low but comparable with Babblers in southern Australia.

The group size of the Babblers at Coomalie Farm ranged from 2-8 individuals and average group size varied little between years. Nesting success and the number of fledglings produced was positively correlated with group size. However, when analysis was considered as reproductive output per individual adult bird group size and fledgling numbers were negatively correlated; as group size increased, fledgling numbers decreased.

Fires occurred regularly at the study site and their timing overlapped with the Babbler breeding season. A series of spatial analysis conducted within a Geographic Information System (GIS) showed no direct impact of fire on Babbler breeding success.

Whilst the results of this study hint that fire might influence the breeding success of the Grey-crowned Babbler in the northern savannas, analyses using the data available were unable to demonstrate any statistical significant association.

Further research involving clear definition of Babbler territories and a more complete fire history would enable the impact of fire on breeding success to be better understood.
Chapter 1
Introduction, Thesis Overview and Background
1.1 Project definition

1.1.1 Aims of the project
The overarching aim of this project was to determine the effect, if any, of fire on the reproductive ecology of the Grey-crowned Babbler, *Pomatostomus temporalis*, in the Top End savannas. Within this broad objective there were several sub-aims:

1. To determine the breeding success of Babblers at a specific study site in the northern savannas and whether it is significantly different to that seen in studies in southern Australia;
2. To investigate the relationship between group size and breeding success and group size and number of fledglings produced;
3. With specific respect to fire:
   - To explore whether there was a difference in breeding success between burnt and unburnt nest sites;
   - To investigate the effect of the fire history of a nesting site on breeding outcomes;
   - To examine breeding results with respect to the timing of fire within a given year.

1.1.2 Focus of study
The study species of this project is the Grey-crowned Babbler, *Pomatostomus temporalis*, a gregarious, endearingly social bird found across much of Australia including the tropical savanna woodlands of northern Australia. Its decline in southern Australia is well documented (King 1974; Robinson 1993; Adam and Robinson 1996) and, whilst its conservation status is considered secure in the Northern Territory (Higgins and Peter 2002), a recent study has indicated that its breeding success in the tropical savannas is relatively low (Eguchi *et al.* 2007).

Fire, or fire regimes, form a prominent aspect of the environment in which the Babblers of the Australian tropical savannas live. The effect of fire upon tropical ecosystems is an increasing area of research in northern Australia and how fire regimes affect the variety of flora and fauna in this area needs to be better understood to contribute to management of this biome. Fire is given special attention in this project with regards to
its effect upon Babbler breeding ecology.

This study specifically focuses on the breeding ecology of a population of Grey-crowned Babblers at a study site in the northern savannas and the impact of the regular fires that occur in the area.

1.1.3 The need for this research
Much research has been undertaken relating to the impact of single fire events on birds (Pyke et al. 1995; Loyn 1997; Recher 1997); however, few have investigated the effects of repeated fires as is the case in the Top End. Of those studies that have been conducted on fire in the savanna ecosystems only a small proportion has focussed on the impact of fire on reproductive ecology.

1.1.4 The contribution of this thesis
This thesis aims to help fill the gaps in knowledge of the effect of fire on the reproductive patterning and success of a tropical cooperatively breeding bird species.

The research undertaken in this thesis falls under the umbrella of the Memorandum of Understanding between Charles Darwin University and Kyushu University. It complements the studies by Associate Professor Eguchi and his colleagues by utilising their demographic data to look at the effects of fire on this species. It adds to the store of knowledge being gathered regarding the management of savannas in the Northern Territory and further validates the use of spatial science to help formulate management strategies regarding biodiversity and land use.

1.2 Approach
Using five years of breeding data, I considered factors that affect the breeding success rate of Babbler groups in a tropical savanna environment. As Babblers are a cooperatively breeding species, group size was singled out so as to investigate its influence on breeding success and to compare results with those of studies on southern Babblers.

As this study was started several years after the initial breeding data were collected, satellite imagery was used retrospectively to determine fire patterns across the study site. This allowed the project to be approached from a spatial science perspective.
instead of having to rely on large amounts of field data. A Geographic Information System (GIS) was used to store and collate spatial data which were subsequently used in the analysis of fire patterns and breeding results.

### 1.3 Thesis overview

This thesis explores the breeding success of the Grey-crowned Babbler in the Top End savannas with respect to two important variables, group size and fire. This study utilises time series spatial data in a GIS to provide information on the study site for the study period in an attempt to collate a simple fire history of the area and to observe changes in fire patterns across time.

Following in this chapter savannas, the biome into which the habitat of the study site falls, are discussed within a global and local context. The specific ecosystem process being investigated (fire) is described and the study species, the Grey-crowned Babbler, is introduced along with a general discussion of birds and cooperative breeding as it relates to the project. A concise introduction to the Geographic Information System (GIS), is also included.

Chapters 2 and 3 are methodological in nature. Chapter 2 outlines the study site, the data used and its acquisition, whilst chapter 3 describes in detail the spatial data gathered, it’s processing and implementation within the GIS.

Chapters 4 and 5 are results chapters. Chapter 4 is a general consideration of breeding success and determines the reproductive success at the study site. It also addresses the question of the influence of group size on breeding success and compares this to studies of Babblers in southern Australia. Chapter 5 considers fire and its effect on breeding outcomes of Babbler groups.

An overall summary of the results is presented in chapter 6 along with an assessment of the use of GIS and spatial science in this project and a discussion of the effectiveness of these techniques when using retrospective data.

The thesis concludes with a discussion of management implications and potential future research that could assist in better understanding the effect of fire on Babbler populations in the tropical savannas.
1.3.1 Terminology
Throughout this thesis the term ‘Top End’ refers to the area of the Northern Territory north of 18°S.

The Grey-crowned Babbler, *Pomatostomus temporalis* is referred to as ‘Grey-crowned Babbler’ or ‘Babbler’.

1.4 Background
This section gives background information on savannas (definition, significance and a global context). The role of fire as an important natural and introduced ecosystem process in the tropical savannas of the Northern Territory is explored. Birds of this region are also discussed with a particular emphasis on Babblers. The relationship between Australian birds and the impact of fire is discussed and the particular reproductive system of the study species, cooperative breeding, is considered. The study species itself (the Grey-crowned Babbler) is introduced and the chapter concludes with a look at the role of GIS and landscape ecology as it applies to this project.

1.4.1 Savannas and their significance
Savannas cover almost one third of the world’s land surface, being found on four continents: Africa, South America, Asia and Australia, and support more than twenty percent of the global human population (Mistry 2000). At its most basic the definition of savanna is “tropical grassland with scattered trees” (Bourliere and Hadley 1983). However there are a broad range of definitions relating to both climatic and vegetative variations of these communities.

Sarmiento (1983) used seasonality to divide savannas into four functional types:

1. Semi-seasonal: those that exist with minor water stress (i.e. have a mostly wet climate) and have few adaptations to fire. This type of savanna is found within rainforest belts such as those in South America;
2. Seasonal: those having a defined wet and dry season with fires being a regular component during the drier times. These savannas are the most widespread of the climatic types and are found in Australia, Africa and South America;
3. Hyperseasonal: savannas that experience a defined wet and dry season and also
flooding that causes a ‘water logging’ stress to the plants. Sometimes known as ‘poorly drained savannas’, these are found predominantly in South America and Australia;

4. Esteros: wetland or swamp savannas. These areas have an abundance of soil water throughout the year and no clearly defined dry season. Considered by many not to be typical savannas.

The majority of savannas found around the world are ‘natural’; however, there are also large tracts of ‘derived’ savannas caused by human disturbance. African and Asian savannas have long been impacted by human agriculture but it is in India that the most drastic formation of ‘derived’ savannas has occurred (Mistry 2000). Misra (1983) suggested that only 10% of India’s original tropical forests exist with land clearing for agriculture causing the transformation into grasslands.

Around 20% of the Australian continent is covered by savannas and these dominate the vegetative landscape of the Northern Territory at over 40% of the habitat (Andersen et al. 1998; Williams and Cook 2001b; Williams et al. 2002). The majority of Australian savanna woodlands are found in the sub coastal, well-drained lowlands (Dunlop and Webb 1991) and their vegetative composition varies with soil types and rainfall. Top End savanna woodlands are dominated by Eucalypts with *Eucalyptus tetrodonta* and *E.miniata* being the most common tree species, often in conjunction with *Corymbia* spp (Lonsdale and Braithwaite 1994; Fox et al. 2001). Tall tussock grasses, most notably of sorghum *Sarga* spp, dominate the understorey (Fox et al. 2001).

The savannas of the Top End of the Northern Territory are subject to year-round high temperatures and a well-defined wet season with approximately ninety percent of the annual rainfall of around 2000mm (Bureau of Meterology 2010) falling between November and April (Vardon and Noske 1998; Spessa et al 2005). The dry-wet transition months of October and November see occasional thunderstorms, but the wet season generally begins around late December, largely determined by the position of the monsoon trough (Bureau of Meterology 1998).

Globally, savannas have a long history of human occupation and use (Hadley 1985). In particular African and Asian savannas have experienced a great deal of modification due to several thousand years of agricultural and grazing practices (Mistry 2000). However, human modification of the Australian savannas has been, until recently, fairly limited to
the consequences of broad-scale fire management (Bourliere 1983; Tothill et al. 1985; House and Hall 2001).

Due to the relatively low levels of land clearing in the Northern Territory (less than 2 percent (Scanlon et al. 1991; Hosking 2002)), the savannas are largely intact but they are prone to frequent fires during the dry season (Dyer et al. 2001a; Andersen et al. 2003). The primary human use of the Top End savannas is pastoralism (Dyer et al. 2001b). Over time, grazing has caused changes to the vegetative composition of savannas, contributed to the introduction of feral flora and fauna and altered the fire regimes (Russell-Smith et al. 2003; Woinarski and Fisher 2003). Mining and tourism have recently become major industries in the savannas but, although intense in that they place high levels of stress on their immediate natural environments (localised vegetative disturbance or clearing for example), their impacts are limited to relatively small areas (Ash and McIvor 1998; Savanna Explorer North Australia Information Resource 2005). Defence force training and nature conservation areas also utilise the savannas to a smaller extent (McIvor et al. 1994; Woinarski and Ash 2002).

1.4.2 Fire in the Top End savannas

Fire has played an important role in shaping the Australian landscape and today, northern Australia is home to the most frequently occurring and largest fires in the country (Dyer et al. 2001b; Williams et al. 2002). Living with annual fires and finding and maintaining the most suitable fire regimes for both the natural ecosystems and human land users is a continual challenge for land managers (Hadley 1985; Allan et al. 2001; Beringer et al. 2007).

At this point it is pertinent to define and explain the concept of a ‘fire regime’ as opposed to a ‘fire’ per se. A fire itself is a single event whereas a fire regime, as it is described by Gill and Bradstock (2003 pg16) “is a sequence of fire events defined by ‘between-fire interval’, ‘intensity’, ‘seasonality’ and ‘type of fire’”. Put more simply, the term ‘fire regime’ refers to when and how frequently an area is burned taking into account the size, intensity and mosaic of burning (Williams and Cook 2001a). Unlike temperate Australia, where a single, devastating fire event may be a primary focus, in the Northern Territory it is the fire regime of an area that is of particular interest and of use to researchers (Andersen et al. 1998; Gill et al. 2003). This study is the same in that it is the fire regime that is most likely to impact on birds.
Fires and fire regimes can have both short-term and long-term effects on an ecosystem. The most obvious, immediate effect is the damage to vegetation, injuries to native fauna and livestock and, on occasion, human fatalities and infrastructure damage. In the longer term fires may indirectly alter the structure of the environment they occur in by causing change to the species composition, both floral and faunal, of an area. In conjunction with other environmental pressures, such as land clearing and livestock impact, fire may also contribute to detrimental habitat fragmentation (Berryman 2006; Regan et al. 2010). Air quality, too, is affected by fires and fire regimes (Radke et al. 2001; Tattaris et al. 2010). Fires occurring in tropical savannas are now being recognised as a major contributor to greenhouse gases (Australian Greenhouse Office 2007; Beringer et al. 2007; Yates et al. 2008) and a correlation has been shown between the incidences of asthma patients at the Royal Darwin Hospital and the levels of particulate matter released during severe dry season fires (Johnston et al. 2002).

Of the major global habitats, savannas are considered the most fire-prone (Yates et al. 2008). The tropical savannas of the Top End of Australia are particularly susceptible to frequent fires (Williams and Cook 2001a) and data relating to fire events show that this area is the most fire-prone in Australia (Russell-Smith and Yates 2007; Yates et al. 2008). All aspects of savanna ecology are affected by fire (Russell-Smith et al. 2001) and fire regimes are, in turn, affected by human land use. The impact of fire varies across the savanna landscape dependent on the fire regime (Andersen 2003; Beringer et al. 2007).

Prior to human settlement, the primary ignition source for fire on the savannas was lightning during the build-up and early wet season periods (Braithwaite 1996). Upon the arrival of Aboriginal people, ca 60 000 years ago, human activity became the major cause of savanna fires (Gill et al. 1990; Williams and Cook 2001a). Traditional Aboriginal burning practices appear to have involved burning small areas throughout the year (Dyer et al. 2001b; Williams and Cook 2001a). This altered the natural fire regime from one in which fires occurred mostly during the transitional periods between the dry and the wet seasons, to a regime of fires commonly occurring all through the dry season. The arrival of Europeans, their domestic livestock and farming practices altered fire regimes still further (Dyer et al. 2001b; Bowman 2003). Fire regimes were modified from the traditional indigenous ways of varying the size and season of burning according to the location (Gill et al. 2003) to a regime of extensive, frequent late-dry season fires to maximise pasture growth (Williams and Cook 2001a). As many animals
require a mixture of habitat types (e.g. one for breeding, one for foraging etc) the resulting loss of patchiness of habitats within the landscape can lead to a loss of biodiversity as species are forced out (Williams and Cook 2001a; Andersen 2003).

The markedly seasonal wet-dry climate of the Top End constrains the distribution of closed forest systems and favours savannas with their high levels of grassy understoreys. The curing of the grasses in the dry season provides fuel for subsequent fires (Liedloff and Cook 2007) and has much influence on their frequency and intensity (Williams et al. 2002).

Due primarily to the population distribution, as with many areas of ecological research, much of the focus of fire studies has been in the temperate zone of southern Australia or overseas; however, as the focus of potential food production and water resources has turned to the northern part of the continent, there has been an increase in research into fire in the tropical savannas of the Top End (see: Dyer et al. 2001a; Gill et al. 2003; Yates et al. 2008 among others). Several studies (Begg et al. 1981; Woinarski 1990; Recher 1997; Gill et al. 1999; Williams et al. 2002; Woinarski et al. 2004; Andersen et al. 2005) have examined the effects of fire on the ecosystems of Top End savannas, but only a few have focused on its impact on reproductive patterning and success for any animal species (Begg et al. 1981 with small mammals; Nicholson et al. 2006 with skinks).

It has been speculated that the regional and local composition of faunal communities may be heavily influenced by fire regimes (Begg et al. 1981; Kerle and Burgman 1984; Trainor and Woinarski 1994). However, studies to date have been primarily concerned with effects at the community level rather than at the population or species level (Williams et al. 1999). Special mention, however, must be made of the Kapalga experiment, a large-scale study of an area of savanna woodland and open forests within Kadadu National Park (Andersen et al. 2003). It is especially noteworthy for its experimental imposition of contrasting fire regimes and fire impact on the ecosystems in the region over a five-year period. Two intriguing trends were found in this broad-reaching study. Firstly, of the species considered, the majority of populations were unaffected by fire over the time span of the experiment. Vertebrate and invertebrate groups showed minimal change in abundance and species richness as did the plant communities comprising the savanna grass layer. It was concluded that much of the
biota of the savanna in this area was resilient to fire (Andersen et al. 2005). Secondly, it was found that when fire did have a significant effect it was between burnt and unburnt habitats, regardless of when fire occurred (early or late dry season) (Andersen et al. 2005). This study considers the same variables with regard to fire and Babbler breeding results: whether a site is burned or unburned and whether the timing of fire is significant.

1.4.3 Birds in the tropical savannas
The savannas of the Top End of the Northern Territory fall into the Torresian subregion of the three biogeographic regions of Australia as proposed by Baldwin Spencer in the 1890s (Burkhill 1941). The Torresian subregion can be further divided into the Top End, the Kimberley and Cape York subregions (Ford 1978; Keast 1981). The strong seasonality of the Top End caused by the annual monsoon is thought to be the most influential ecological factor affecting the life of birds in this region and may be one of the reasons that birds in this area are found to be flexible in their use of habitats (Morton and Brennan 1991).

Low levels of land clearing have meant that the Top End bird assemblage has suffered significantly fewer habitat disturbances, the single greatest threat to bird species, than that of temperate Australia (Gillison 1983; Mott et al. 1985; Andersen et al. 1998). In fact, northern Australia now provides important refuges to species that have declined elsewhere including the Red-tailed Black Cockatoo (Calyptorhynchus banksii); the Bush Stone-curlew (Burhinus grallarius) and, the focus of this study, the Grey-crowned Babbler (Woinarski 2005a). However, the birds of the tropical savannas face threats from feral species (e.g. cats and buffalo) and also have to contend with the regime of frequent fires (Woinarski 2005b) which this thesis hypothesises may impact upon Babbler breeding outcomes.

1.4.4 Birds and fire
At the species level, inappropriate fire regimes have been considered an important contributing factor to the decline of some threatened bird species (Woinarski 1990; Woinarski and Recher 1997; Garnett and Brook 2007). There have been direct effects such as in the case of the critically endangered Helmeted Honeyeater (Lichenostomus melanops cassidix) of West Gippsland in Victoria that suffered the destruction of colonies in the Ash Wednesday fires of 1983 (Baker-Gabb 1992; Menkhorst 2008)
further damaging already fragile populations, and indirect effects such as those seen with the Black-eared Miner (*Manorina melanotis*) (Clarke et al. 2005). A combination of clearing for agriculture and changed fire regimes has led to the invasion of the Black-eared Miner habitats in the Murray Mallee region by Yellow-throated Miners (*Manorina flavigula*). This other species is now interbreeding with the Black-eared Miner and overwhelming most populations (Clarke 2005).

The impact of fire on bird species is not easy to predict and it is rarely the sole cause of population declines, but it may be the final decisive blow that forces some species to the brink of extinction. The Eastern Bristlebird, *Dasyornis brachypterus*, of southeastern Australia suffered greatly due to habitat loss but now the remaining populations found in protected areas are at risk of further major decline due to wildfire contributing to the fragmentation of their habitat (Baker 1997). A further challenge to the northern populations found along the edge of rainforests in Queensland is that the tussock grasses that Bristlebirds in this area prefer are at risk of being shaded out by trees and shrubs unless controlled by fire. To still further complicate things, it has been determined that fire on a too regular basis also threatens Bristlebird habitats by allowing the intrusion of more fire tolerant grass species (Department of Environment and Resource Management 2010). It is apparent in this instance that fire managers of Bristlebird habitats need to find the most advantageous fire regime and patterns to support this endangered species.

Conversely, for some birds fire is primarily beneficial. In northern Australia particularly, some bird species see fire as an aid to gathering food (Braithwaite and Estbergs 1987-88). Raptors such as Whistling Kites (*Haliastur sphenurus*) and Brown Falcons (*Falco berigora*) are attracted to fire fronts where prey species are forced into the open by flames (Braithwaite and Estbergs 1987-88); granivores such as the Gouldian Finch (*Erythrura gouldiae*) also exploit burnt areas where seeds are left exposed by fire (Woinarski 2005). Other species such as the Partridge Pigeon (*Geophaps smithii*) and many finches utilise the immediate bare areas left by fire and move on as the vegetation of the area regenerates (Olsen and Weston 2005. In fact, dense grasses can be a hindrance to many birds when foraging for food e.g. Galahs (*Cacatua roseicapilla*) and Grey-crowned Babblers (Woinarski 2005). With more complexity, Partridge Pigeons and Masked Finches (*Poephila personata*) also require unburnt areas to give them protection from predators when nesting (Fraser et al. 2003; Woinarski 2005b).
Although many studies have been undertaken to investigate the effects of single fires upon birds, there are few that have considered the impacts of repeated fires as seen in the Top End (Meredith 1988; Olsen and Weston 2005) and this is the focus of this project.

1.4.5 Cooperative breeding in birds

Cooperative breeding refers to the system in which a brood is reared by more than two individual birds, the additional birds being known as helpers. Australia is notable for cooperative breeding behaviour among its birds. This continent has more species that breed cooperatively (ca 12% of resident birds species) than any other continent (3.2% globally) (Dow 1980; Arnold and Owens 1998; Cockburn 1998). Several Australians species are considered ‘obligate’ cooperative breeders, because breeding pairs are unable to successfully raise a brood without helpers.

Cooperative breeding is a phenomenon of open habitats and is rarely found in rainforest or other dense habitats (Ford et al. 1988; Cockburn 1998). In Australia, Eucalypt woodlands show particularly large numbers of cooperatively breeding species and many credit the prevalence of communal breeding birds to the low seasonality of this habitat (in the southern temperate region; the tropical woodlands of the northern savannas are highly seasonal) (Brown 1987; Ford et al. 1988). However, there are differences of opinion whether or not seasonality is a major factor in the evolution of cooperative breeding (Heinsohn et al. 1990; Cockburn 1998). Birds that use this particular breeding system are not easy to categorise (Ford et al. 1988; Arnold and Owens 1998), but many tend to be long-lived, sedentary and territorial (Brown 1978, 1987). Group sizes range from three (breeding pair plus one helper) to over a dozen.

The costs of cooperative breeding are few (Raitt et al. 1984; Ford et al. 1988; Clarke 1995); however Heinsohn and Cockburn (1994) noted that in White-winged Choughs (Corcorax melanorhamphos) helper birds in small groups risked health and, ultimately, survival by aiding in the incubation of eggs. Courchamp et al. (2000) further suggested that the presence of helper birds in the nesting territory may provide an attraction for predators as well as brood-parasites (cuckoos). Helpers themselves may pay the price of suppression or delay of sexual maturity thus reducing their own chances of passing on their genes (Taborsky 1984; Reyer et al. 1986). It may also be speculated that, due to the increased number of birds required for successful breeding, increased resources
are needed and, thus, cooperative breeders may be even more sensitive to habitat fragmentation than those birds that do not reproduce in this manner. Therefore, it may be reasonable to presume that cooperative breeders may be vulnerable to inappropriate fire regimes (Brooker and Brooker 1994; Garnett and Crowley 1995).

1.4.6 The Grey-crowned Babbler
The Grey-crowned Babbler, Pomatostomus temporalis, belongs to the family Pomatostomidae (Pseudo-Babblers), a small group of five species in one genus restricted to Australia and New Guinea. Although once widespread across north, north-western, central and eastern Australia (Figure 1.1), the Grey-crowned Babbler is now threatened in South Australia, endangered in Victoria and vulnerable in New South Wales, due predominantly to habitat fragmentation and predation by feral species such as cats and foxes (Davidson and Robinson 1992; Schodde and Mason 1999; Clayton et al. 2006). Higgins and Peter (2002) list P. temporalis as extinct in South Australia. Two races of P. temporalis are recognised: P. temporalis temporalis in eastern Australia from Victoria to Cape York Peninsula; and P. temporalis rubeculus occurring in the Northern Territory, Western Australia, limited northern areas of South Australia and western Queensland (Schodde and Mason 1999). The Northern Territory populations of the Grey-crowned Babbler are considered secure at this stage (Clayton et al. 2006), largely due to the integrity of their habitats: the open woodlands and forests of the tropical savannas.

The Grey-crowned Babbler is a distinctive bird. They are the largest of the Babblers, 23-29cm long, with a curved beak and dark-brown eye stripe bordered by a broad white eyebrow (Simpson et al. 1999), giving them the semblance of wearing a mask. The body is grey-brown in colour. P. t. temporalis has a white breast merging to grey whereas P. t. rubeculus has a red-brown ‘rufous’ breast (Figure 1.2). Social, active and noisy birds, they are commonly found in groups ranging from four to twelve individuals (Higgins and Peter 2002). Territories are vigorously defended (Counsilman 1977, 1980; King 1980; Eguchi et al. 2007). Their calls have been described as loud ‘yahoo’, cat-like meowing and chirring (King 1974; Simpson et al. 1999). They are predominantly insectivorous but occasionally eat seeds (Higgins and Peter 2002). The curved beak is used to probe under bark and leaf litter for insects. As an obligate cooperative breeder, P. temporalis is reliant on helpers to successfully raise chicks.
The breeding data used in this study came from a six-year project undertaken on this species in the Northern Territory by a team of researchers led by Associate Professor Kazuhiro Eguchi and Professor Keisuke Ueda from Kyushu and Rikkyo Universities, Japan. That project is the first study to investigate the life history of *P. temporalis* in the tropics.

**Figure 1.1** Distribution map of the Grey-crowned Babbler, *Pomatostomus temporalis* across Australia (Map courtesy Birds Australia Birdata)
Figure 1.2 *Pomatostomus temporalis rubeculus* (photograph courtesy Mat & Cathy Gilfedder)

1.4.7 The role of landscape ecology

Prior to the 1980s, ecologists did not have the concepts or technologies to easily deal with spatial disparity thus organisms were often grouped into recognisable and undiversified assemblages (Forman and Godron 1986). Vegetation was commonly categorised into community types based on plant species association whereas relationships within and between animal populations, in which observed change occurred more rapidly, was theorised about with regard to temporal dynamics (Mueller-Dombois and Ellenberg 2003). Models arising from such research inevitably assumed a spatially homogenous environment (Kingsland 1995). The advances in computer technology and remote sensing techniques during the last decades of the twentieth century allowed for a revolution in spatial methods and analysis and saw the emergence of landscape ecology as a discipline in its own right (Wu and Loucks 1995).

Whilst still a relatively new and developing aspect of the natural sciences, landscape ecology is proving to be a watershed in its recognition that a landscape is a mosaic of different habitat types, whether the landscape is natural or modified by humans (Bennett 2003). It is now widely accepted in ecological circles that many species
require a certain complexity of habitat to support different aspects of their life cycles rather than a totally homogenous environment (Forman and Godron 1986; Turner 1989; Hansson and Angelstam 1991).

The premise of landscape ecology is the recognition that disturbance, whether by natural or human causes, is the basis for the spatial heterogeneity that is the natural state of ecosystems (Forman and Godron 1986). Or, put another way, natural systems are rarely in a state of complete balance (Wu and Loucks 1995; Wu 2006).

Landscape ecology focuses on three main areas:

1. Landscape pattern: landscape elements and their spatial relationships;
2. Landscape function: interactions within ecosystems; and
3. Landscape change.

(Forman and Godron 1986; Hansson and Angelstam 1991)

Due to the large amounts of often long-term data collected and the wide-ranging geographical areas covered, birds are considered an ideal study organism for landscape ecology and, indeed, landscape ecology is becoming increasingly important in the conservation and management of the world’s avian populations (Flather and Sauer 1996; MacNally and Horrocks 2002). Within Australia, landscape ecological analysis has yielded important information with regards to vulnerable bird species and habitat fragmentation (see: Bennett and Ford 1997; MacNally and Bennett 1997; Manning et al. 2006) as well as helping develop strategies and management plans addressing habitat maintenance and urban development (e.g. Bennett 2003).

Within landscape ecology, fire and its impacts on bird communities in Australia has been reasonably well studied (Woinarski 1990; Brooker and Rowley 1991; Loyn 1997; Woinarski et al. 1999); however, despite studies undertaken in the northern hemisphere (Davis et al. 2000; Artman et al. 2001; Moreira et al. 2003) there is a dearth of research in this area in Australia with respect to the breeding ecology of birds, particularly in the tropical north.

This project takes a landscape ecology perspective in investigating whether fire affects Babbler reproductive ecology in the recognition that a holistic approach to this question is the best way to formulate potential management strategies.
1.4.8 The role of Geographic Information Systems and satellite imagery in ecological studies

Spatial science and spatial analysis has become increasingly important in the understanding and management of ecosystems. The use of Geographic Information Systems (GIS) to portray ecological processes and human interaction with the surrounding environment is now widespread in both social and natural sciences (Mitchell 1999; Wadsworth and Treweek 1999; Fortin and Dale 2005). A GIS may be defined as “a computer-based system to input, store, manipulate, analyse and output spatially referenced data” (Wadsworth and Treweek 1999 pg1). Over the past two decades, GIS have been widely utilised to analyse the threat of both wildfire and controlled burning (Garvey 1994; Chuvieco and Salas 1996; Sriboonpong et al. 2001; Durmaz et al. 2006).

Due to the vastness and remoteness of northern Australia large scale landscape studies requiring extensive field surveys are difficult (Allan and Willson 1995; Ryan et al. 1995) with many areas often inaccessible due to climatic conditions. The use of satellite imagery combined with GIS and digital image processing have become an integral component of the monitoring of fire on the tropical savannas (Hill 1995; Allan et al. 2001) with areas in excess of 185 km² able to be covered in one image alone (Allan et al. 2001; Lillesand et al. 2008). They allow for fire histories to be established that, in turn, provide land management bodies with information on how to better implement and manipulate fire regimes to benefit human use and minimise the impact on the native flora and fauna (Russell-Smith et al. 1997; Edwards et al. 1999; Russell-Smith et al. 2003).

Studies of avian populations with regards to fire, both in Australia and internationally, are also reaping the benefits of this technology. Mills (2004) in a study in Kruger National Park in South Africa utilised satellite technology, in much the same way as this project, to investigate the extent and effect of a large fire on the bird communities of the savannas. A 2003 study by Moreira et al. (2003) in Portugal similarly used retrospective data with a GIS to investigate the effects of prescribed burning on bird populations within pine plantations. Brown et al. (2009) using GIS software to integrate several spatial layers determined that the Mallee Emu-wren, Stipiturus mallee, of south-
eastern Australia is threatened not only by large-scale wildfires but also by an interaction of fire regimes, climate change and population isolation.

Globally, the Moderate Resolution Imaging Spectroradiometer, or MODIS, instrument on NASA’s Aqua and Terra satellites collects daily images of the Earth’s landmasses and is used by many organisations to track and monitor fire activity (Lewis 2004; Sedano et al. 2005). These satellites orbit the Earth every one to two days obtaining information in thirty-six spectral bands with a resolution ranging from 250m to 1km. MODIS imagery is attractive for several reasons: it is often available free of charge; it can provide up to two images a day of an area; the thirty-six spectral bands provide a vast array of information from land boundaries to cloud top altitudes, and is of good radiometric resolution (Silva et al. 2007). The major drawback to MODIS imagery is that its resolution is better suited to large scale mapping; that is, studies of smaller areas requiring a finer resolution would not find MODIS imagery as useful as some alternative image providers due to the level of detail visible.

The two major satellite sensors currently used for fire monitoring and mapping in the Top End are onboard the Landsat satellites, jointly run by NASA (National Aeronautics and Space Administration) and the United States Geological Survey, and the NOAA (National and Oceanographic Atmospheric Administration) satellites with their primary sensor the Advanced Very High Resolution Radiometer (AVHRR). The mapping of Australia by NOAA AVHRR technology has been ongoing since the early 1980s (Russell-Smith et al. 2003). During the dry season, NOAA AVHRR and MODIS images of fires are mapped by the Western Australian Department of Land Administration (DOLA) and subsequently distributed throughout the Northern Territory by the Bushfires NT Council (Edwards et al. 1999). NOAA AVHRR imagery provides information on ‘fire-scars’ (fire history or the extent of fire) and ‘hot spots’, literally an area where there is an active fire. The NOAA satellites operate on nine-day orbits (Allan et al. 2001). One drawback of this particular imagery is that it is considered relatively ‘coarse’ (minimum 1.1km² pixel size). Landsat imagery, alternatively, gathered in a sixteen-day orbit, is of a finer resolution (30m² pixel size in multispectral images) and is useful in determining regional fire regimes.
1.4.9 Summary

This chapter provides a background to the ensuing study and illustrates the importance of a spatial approach to understanding tropical avian distributions and habitats. Principles of landscape ecology provide a framework from which this can be undertaken and, thus, a landscape ecological position is taken in this project.

The study species is placed within a regional and national context and the concept of cooperative breeding is explored with respect to the themes in this research.
Chapter 2
Study Site and Data Sources
Chapter outline
This chapter provides a detailed description of the study site within the Coomalie region of the Northern Territory. Topographic maps provide a visual context of the location of the site as it pertains to the local and national scale. Some examples of the vegetation of the site are shown and the climate of the area is explained along with mention of the fire regime affecting the area. The acquisition and application of satellite image data are covered including an explanation of Landsat imagery and its composition; the processing of data sets is described. The Babbler breeding data used are introduced and sources of information are acknowledged.

2.1 Description of study site

Location
The study was conducted at Coomalie Farm (13°00’S, 131°08’E), a privately owned landholding of around 24km² within the Coomalie sub-region approximately 80km South of Darwin (Figure 2.1). The farm is primarily kept as a nature reserve and is used for ecological research. Cattle and Buffalo are occasionally found in the area and defence force exercises are conducted on the farm from time to time. There is a small amount of tourism as the farm is home to several World War Two sites.

Vegetation, Hydrology and Geology
Savannas dominate the area comprising woodlands, open forest and grasslands. Over 70% of the Coomalie sub-region is made up of this habitat type (Price and Baker 2003). Eucalyptus and Corymbia species dominate the woodlands and forests with Sarga spp making up the understorey and grasslands(Eguchi et al. 2007). Melaleuca floodplains are also represented along with a limited amount of riparian vegetation. The common weed species Gamba Grass (Andropogon gayanus), Mission Grass (Pennisetum polystachion) and Mimosa (Mimosa pigra) are also found extensively through the region (Price and Baker 2003).

The hydrology of the sub-region constitutes the Adelaide River floodplain along with the river systems of the Adelaide, Margaret and Finnis Rivers (Environment Australia 2001).
The man made catchments of Darwin River Dam (Darwin and surrounding areas main potable water supply), Lake Bennett and Manton Dam are all found within the area (Price and Baker 2003). Coomalie Creek runs through the farm providing a year-round source of water.

The Coomalie sub-region falls within the Palaeoproterozoic Pine Creek Geosyncline which encompasses 66000 km² east and south of Darwin (Department of Lands 2000).

**Climate**

The farm is subject to the Top End climate of a well-defined wet and dry season. The dry season runs from May to September and is characterised by lower temperatures, low humidity and little to no rainfall. The dry-wet transition occurs during October/November. Humidity and temperature levels increase and occasional thunderstorms may form. The true wet season begins in December and is largely determined by the position of the annual monsoon trough (Bureau of Meteorology 1998). Though the wet season is typified by periods of sustained rainfall, protracted dry spells are not uncommon (McDonald and McAlpine 1991) (Figures 2.2 & 2.3). The Coomalie region experiences between 1150-1360 mm annually (Bureau of Meterology 2010) with approximately ninety percent of the annual rainfall falling between November and April (Williams and Cook 2001b; Spessa et al. 2005).

**Fire**

Fires occur frequently at Coomalie Farm. Controlled burning is often carried out early in the dry season (April/May/June) to provide fire breaks but the majority of wild fires occur in the mid to late dry (July to October) (Department of Lands 2000; Price and Baker 2003) when the copious wet-season growth has dried out almost completely. The mid dry season fires largely remove the understorey of grass with little damage to larger vegetation; however, late fires cause serious scorching to trees sometimes reaching the canopies (Figure 2.4). Fires may also occur in the early wet season, November/December, providing conditions are conducive to fire and there is fuel available (Williams and Cook 2001a).
Figure 2.1 Location of Study Site at Coomalie Farm relative to Darwin (Map created using data courtesy of Geoscience Australia Copyright Commonwealth of Australia; note: white areas comprise built-up areas, cleared areas and areas uncategorised by map creators.)
Figure 2.2 Coomalie study site February 2008 (wet season); wet season monsoons cause vigorous vegetation growth.
Figure 2.3 Coomalie study site May 2008 (dry season); understorey grasses are drying out and the fuel load is becoming combustible.
Figure 2.4 Coomalie study site after fire August 2007; understorey vegetation has been burnt away and scorching is visible on tree trunks.
2.2 Description of data

2.2.1 Pre-existing data

Data used in this project were largely retrospective. The satellite imagery ranged from years 2002-2007 as did the breeding data. These data are described in more detail below. Auxiliary spatial data for the study site, largely topographic, vegetation and other useful boundary information for the region, were in the form of ESRI shapefiles (Environmental Systems Research Institute 1998). A shapefile “stores non-topological geometry and attribute information for the spatial features in a dataset. The geometry for a feature is stored as a shape comprising a set of vector coordinates. Shapefiles can support point, line, and area features” (Environmental Systems Research Institute 1998 pg1)

2.2.1.1 Landsat images

Forty eight images taken by the Landsat-5TM satellite system across the study region from 2002 to 2007 were provided by the Northern Territory Government’s Department of Natural Resources, Environment, the Arts and Sport (NRETAS) and further images were obtained courtesy of Rohan Fisher of the Tropical Spatial Sciences group at Charles Darwin University. Two per year for the years 2003-2007 were chosen. The images selected cover the mid-to-late dry season. Landsat Thematic Mapper (TM) images were chosen over Moderate Resolution Imaging Spectroradiometer (MODIS) imagery due to its higher resolution being more applicable for smaller study areas. Pixel cell size of individual images ranged from 25 x 25 m to 33 x 33 m.

The Thematic Mapper (TM) sensor on board the satellite records electromagnetic radiation in seven discrete bands (National Aeronautics and Space Administration 2010). Due to the spectral bands used by Landsat, the images are False Colour Composite (FCC); that is, objects in the image may be in colours not considered natural or intuitive e.g. vegetation instead of appearing green may appear as blue or red (Jensen 1996). The colours used represent how brightly an object reflects electromagnetic radiation in a particular band and what colour has been designated to that band. Resolution of Landsat imagery is 30 m²; however as pixel (cell) size is a function of both the sensor (optics and sampling rate) and the platform (altitude and velocity) some slight variation in pixel size is not unexpected.
Images had the typical fire and vegetation mapping band combinations of 3, 4, 5; 3, 4, 7 and 3, 5, 7. Visible red band 3 is commonly used to differentiate between vegetation types and measure chlorophyll absorption; near-infrared band 4 is used to determine healthy vegetation and discriminates fire scars from other ground covers; mid-infrared band 5 is useful in ascertaining moisture contents of soil and vegetation; and mid-infrared (shortwave infrared) band 7 is sensitive to ground exposure and soil changes following fires (Lillesand et al. 2008; National Aeronautics and Space Administration 2010) (see example Figure 2.5). Images had been rectified and georeferenced (i.e. had a coordinate system assigned) prior to acquisition by the supplier.
Figure 2.5 Landsat false colour composite image of part of Coomalie subregion with study site boundary overlaid. Bands 3, 4 and 5 utilised; the large dark purple-black area shows a recent fire (date Sept 2003).
2.2.1.2 GIS data layers
Shapefiles of the region, including a vegetation component were provided by NRETAS. They show a portion of the greater Coomalie area within bounding coordinates:

West: 131.104280; East: 131.278715; North: -12.918726 and South: -13.069808

and the smaller study region within bounding coordinates (Figure 2.6):


These were used to provide a spatial reference for the Landsat images and aid in the derivation of fire maps for the study site.

Topographic maps at 1:250 000 scale of the Darwin and Pine Creek region (both were needed to cover the study area) were obtained in GIS data layer form from Geoscience Australia, an Australian Government agency within the Resources, Energy and Tourism portfolio (Department of Energy Resources and Tourism 2010). Each map set contained comprehensive spatial data for the cartography, elevation, framework, habitation, hydrography, infrastructure, terrain, transport, utilities and vegetation of the specified area covered (see example image Figure 2.7). These were used to put the study site within a regional context and also to see how much human development was occurring around the Babbler breeding areas. It also aided in validating satellite images by providing broader scale ground control points (e.g. roads and watercourses).

The vegetation component of the shapefiles of the Coomalie region and study site was used in conjunction with field observations of the study site (specifically foraging and nesting locations and a 2006 vegetation survey) and a 1: 1 000000 vegetation map created by NRETAS (formerly the Conservation Commission of the Northern Territory) based on a 1990 vegetation survey of the region to determine the major habitat types (woodland, grassland or open forest) inhabited by Babblers (Figure 2.8).

2.2.1.3 Demographic data for Babblers
The research team led by Eguchi and Ueda provided GPS coordinates of Babbler nest sites from 2002 to 2007. Data relating to breeding success gathered between July and December of each year (number of young fledged, dates of beginning and end of breeding, phase of nest failure) from 2003-2007 have also been shared along with details of group sizes and dates of nest activity (Appendix).
Figure 2.6 Shapefiles of Coomalie Creek region showing study region (Shapefiles provided courtesy of NRETAS) (Robinson et al. 1972)

1 Data source: Land and Water Division, Department of Natural Resources, Environment and the Arts, Northern Territory Government.

Land resource information: Land resource information has been derived from aerial photograph interpretation and field data describing landform, soils and vegetation collected according to Australian Soil and Land Survey Standards at time of capture. This survey data has been prepared at a scale of 1:25,000. Enlarging the data beyond this scale will not provide further detail. Field verification should always accompany any mapping over specific areas.
Figure 2.7 Example of topographic map data layers as supplied by Geoscience Australia (Copyright Commonwealth of Australia).
Figure 2.8 Major habitat types of the study site at Coomalie Farm (Shapefile and data provided courtesy of NRETAS) (Robinson et al. 1972; Wilson et al 1990; Personal observations 2006)

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2 Data source: Land and Water Division, Department of Natural Resources, Environment and the Arts, Northern Territory Government.

Land resource information: Land resource information has been derived from aerial photograph interpretation and field data describing landform, soils and vegetation collected according to Australian Soil and Land Survey Standards at time of capture. This survey data has been prepared at a scale of 1:25,000. Enlarging the data beyond this scale will not provide further detail. Field verification should always accompany any mapping over specific areas.
2.3 Summary
Coomalie Farm lies approximately 80 km South of Darwin and is comprised primarily of savanna woodlands and grasslands. The climate is that of the Top End well-defined dry and wet seasons, with fires occurring throughout the dry season (April-October) and occasionally into the wet season (November-March).

Landsat images of the region for the early-mid dry (May-July) and lat dry (August-October) were obtained, rectified and georeferenced, from NRETAS. Shapefiles of the area (containing a vegetation component) were also attained from the above agency and were used to provide a spatial reference for the Landsat images. The vegetation data provided aided in confirming the preferred nesting habitat of Babblers.

Caveat
Although I have attempted to obtain the most accurate and recent data available it remains that some (e.g. vegetation data from shapefiles) could be outdated. Fieldwork aids in verifying the general accuracy of data; however, with the Landsat imagery being retrospective, this is challenging. Images were only taken on particular dates, significantly apart. An image with no fire recorded on July 1 2006 does not mean a fire did not occur on July 2 for example.

The Babbler breeding ecology data have similar drawbacks. The data recorded depended very much on the observational skills of the researcher at the time, and, as Babblers have been noted to breed as early as June and as late as the following February, some breeding data may have been unrecorded simply due to researchers not being on site.

I have attempted to resolve these issues as much as possible in subsequent analysis.
Chapter 3
A Spatial and Temporal Analysis of the Coomalie Landscape:
Quantification of Fire Patterns
Chapter outline

This chapter explores the methodology applied to conduct a spatial and temporal analysis of the Coomalie region. Babbler breeding data were collected several years prior to the start of this research project therefore satellite images provide an effective way of viewing the impact of the natural processes in the landscape (specifically fire) that occurred across the years the Babbler data were collected. The use of satellite imagery is advantageous for this type of study in that it can cover the entire study site area and, thus, enable data to be collected on the total amount of habitat experiencing fire. These data are used in the analysis conducted later in this study. This reduces considerably the need for extensive fieldwork.

The way in which the satellite images were processed and classified for use in the GIS database is explained in this chapter along with an accuracy assessment of final images. The determination of fire patterns across the study site is also discussed.

3.1 Why use satellite imagery?

The decision to use satellite imagery in this project was due to the fact that the gathering of Babbler breeding data had begun several years prior to this study. It was determined that the most accurate records of fire across the study site could be obtained in this manner; the alternative was anecdotal evidence of landholders which, whilst not implying any untruth, would be reliant on the landholder being present during fire, assessing the impact of fires and estimating the extent of fire.

There are several advantages to using satellite imagery for a project such as this. Primarily for this study, because there was fire data in the form of satellite imagery available for the years required, it meant that a five-year breeding history could be analysed. The fact that one image covers 185 km² is a tremendous advantage in that the need for fieldwork is reduced or negated altogether. More generally, satellite images are a convenient means of observing and measuring landscape patterns and change over time, as the spatial composition of landcovers can be observed in a digital mosaic (Chuvieco 1999).

Globally, this is by no means the first project to use this technology from a landscape
ecology perspective for avian studies. As early as 1997 Hepinstall and Sader (1997) used Landsat imagery for developing predictive models of bird occurrence in Maine, USA, citing the higher costs and greater time consumption of creating standard habitat maps as a primary reason for choosing this method. The spatial distribution of breeding habitats in shrubland birds in south-western Idaho, USA, the habitat change (particularly due to changes in fire regimes), and current habitats was quantified using satellite imagery and GIS analysis in a study undertaken by Knick and Rotenberry (1999, 2000). Saab et al. (2009), too, observed the impacts on the breeding ecology of avian communities in the United States using pre- and post-fire satellite imagery from Landsat satellites.

Although the use of satellite imagery is becoming increasingly utilised in the monitoring and management of fires in Australia (Craig et al. 1995; Bowman et al. 2003; Edwards et al. 2003; Beringer et al. 2007) very few studies have specifically used this technology and applied it to the study of avian reproductive ecology with regards to fire. It is hoped that this project will be an example of how useful satellite imagery can be for such research.

### 3.2 Image classification

To extract information classes (e.g. fire category), from the multiband images, data were subjected to image classification methods. The data were imported to ERDAS Imagine 9 (ERDAS Inc 2008) to be subset to the study area. Following subsetting, images were scrutinised to determine whether masking of clouds and their shadows was required. Masking was necessary for only one image, September 2006 when small patches of cloud shadow were on the image.

#### 3.2.1 Unsupervised classification

An unsupervised classification of each fire image was carried out in ERDAS Imagine 9.2 after images had been subset. Unsupervised classification does not require the user to specify any information regarding features in the imagery, thus the classification relies purely on the software analysis of the images (Jensen 1996). This method in ERDAS Imagine uses the Iterative Self-Organising Data Analysis Technique algorithm (ISODATA) to form clusters based on the minimum spectral distance; that is, the programme
groups pixels based on spectral similarities. There are several benefits to using this method. It is an extremely effective method of identifying spectral clusters in data; very little user effort is required and the classifier does not need to know much about the data beforehand.

Six spectral classes were chosen to delineate between areas; as per standard protocol, categories were assigned to the resultant classes after the unsupervised classification. This was done by overlaying the unsupervised classification on the original false colour composite image (see methods in Jensen 1996) (Figure 3.1).

The classes that were determined from this procedure were:

- Recent fire or a water body;
- Recent fire;
- Early fire;
- Unburned;
- Bare earth

In the tropical savannas the evidence of fire, fire scars, can be eradicated by vigorous vegetation growth during the burning season (Eva and Lambin. 1998; Gill et al 2000; Trigg and Flasse 2000). Therefore, it was adjudged that ‘recent fire’ referred to a fire that had occurred between the different times the images were taken i.e. between the early-mid dry season image and late dry season image of any given year with ‘early fire’ being a fire that had occurred prior to or at the time of the early-mid dry season image of a given year. The ‘bare earth’ category relates to areas that have virtually no vegetation e.g. roads or tracks and other cleared areas such as an airstrip. Each image used was classified individually, thus categories vary across time, for example land classified as unburnt in the early-mid dry season image for 2006 may have been categorised as burnt in 2005. Occasionally, these classes overlapped or had more than one category. For example, the ‘early fire’ and ‘bare earth’ classes could overlap when a fire burned away vegetation and, once the ash had been blown away, bare earth was exposed. Also, vegetation may display as more than one class (‘unburned’) depending on stage of growth.
Figure 3.1 Unsupervised classification of Landsat image shown in Figure 2.5; six classes are represented.
3.2.2 Supervised classification

After the unsupervised classification of the fire images was completed, two levels of supervised classification of the resulting classes were performed in ERDAS Imagine. Supervised classification is essentially ‘human-guided’. That is, the user applies their own knowledge of an area to assign pixels to classes. This follows procedures undertaken in several earlier studies where a hybrid method of using unsupervised and supervised techniques were undertaken to classify images (McCracken et al. 1999; Miller and Yool 2002).

Initially, I wanted to determine only whether an area was burned or unburned in a given year. For this the six classes chosen for the unsupervised classification were assessed and merged into three classes (Figure 3.2):

- Burned;
- Unburnt
- Bare earth

Later, when the effect of the seasonal timing of fire was being considered, the six classes from the unsupervised classification were reclassified in a supervised classification and reduced to four (Figure 3.3):

- Recent fire;
- Early fire;
- Unburnt;
- Bare earth

Following accuracy assessment of the supervised images, unsupervised and supervised images were then imported into ArcGIS 9.3 for use in further analysis.

Note: The late dry season image for 2004 did not return a category for early fire; there may be two possibilities for this: either regrowth was more vigorous than other years or more widespread recent fire had covered the area.
Figure 3.2 Supervised classification of Landsat image shown in Figure 2.5; three basic classes are represented.
Figure 3.3 Supervised classification of Landsat image shown in Figure 2.5 to determine timing of fire.
3.2.3 Accuracy assessment of images

There are several sources of error in image classification (Story and Congalton 1986). Errors made by the imaging systems or in pre-processing, interpretation (automated and manual) (Congalton and Mead 1983) and sampling techniques (Hord and Brooner 1976; Congalton et al. 1983) can all impact on the veracity of the finished product. Accuracy of remotely sensed images is commonly determined by comparing the generated classification of areas to field data. Due to the retrospective nature of the project, the accuracy assessment of the fire maps was limited to 2006 and 2007 images (see also: Dennis et al. 2005). Field data from a 2006 vegetation survey and data from foraging observation field work were entered into the Accuracy Assessment tool in ERDAS Imagine 9.3 to determine the accuracy of the supervised classifications of satellite imagery (Table 4.1). Forty-seven points in total were used. The Accuracy Assessment tool compares reference pixels (those pixels for which the correct class is known), in this case field data coordinate points, to the pixels in the classified image. As a limited number of images were used per year, whether I accepted the generated classification of the pixels or not relied somewhat on my own field work and knowledge of the area. For example, foraging data collected in the field in November 2007 might be in an area of significant regrowth. The latest fire map was October 2007 in which the area may have been classified as having been burnt; due to the regrowth in the area I can assume with a reasonable amount of certainty that this classification is correct. Of the points used, an accuracy of 83% was returned (refer to Table 4.1). The numbers listed under the classification headings refer to arbitrary classification numbers assigned by the ERDAS programme.

Congalton (1991) suggests that for areas of less than 5000 km² (½ million Ha), 50 verification points, or ground control points (GCPs) for each class is adequate. However, Bernstein et al. (1983) state that as few as 16 ground control points may be an acceptable number and go so far as to suggest that an increase in the number of GCPs may decrease accuracy as analysts will often select the ‘best’ points. The logistics of this project made the accumulation of a large number of appropriate verification points impossible. Discussions with the landowner and other researchers using the area supported the general accuracy of the classifications and it was deemed that for the purposes of this study this level of accuracy was acceptable (see also: Price and Baker...
Table 3.1 Accuracy assessment table for satellite imagery; note: latitude and longitude has to be converted into Northing and Easting for the ERDAS accuracy program.

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3.3 Determination of fire patterns across the study site

The Patch Analyst extension for ArcGIS: Version 4.2 (Rempel et al. 2008) was used to explore fire patterns across the total area of nesting sites over time. As the individual territories of the Babbler groups were unknown, a nominal territory size of 50ha centred on each nest site was assumed based on the prior work of King (1974), Counsilman (1977) and Adam and Robinson (1996) and each supervised fire image was clipped to the resulting area covered. Raster files were converted to grids in ArcGIS and spatial statistics were generated for each image used. The fire patterning spatial statistics of interest were:

- **Mean Nearest Neighbour (MNN):** a measure of patch isolation.

  This was used to determine whether burnt patches were clustered or dispersed (a result less than 1 indicates clustering, greater than 1 indicates dispersion).

- **Mean Shape Index (MSI):** a measure of shape complexity.

  Used to investigate whether patches were complex in shape as opposed to circular or rectangular.

- **Total Edge (TE):** a measure of the perimeter of patches.

- **Mean Patch Size (MPS).**

  Clarifies the average patch size of the different classes of interest. Potentially this could be used to see whether there is an optimum mean amount of area, burnt or unburnt, required for Babbler breeding success.

- **Number of Patches (NP)**

  The number of patches of the various classes may be useful along with MPS in determining whether Babblers require a certain amount of different patch classes to improve chances of breeding success.

- **Class Area (CA):** the sum of areas of all patches belonging to a given class.

  This was required as I wanted to know how much of the study area was made up of a given spectral class e.g. burnt or unburnt.

The results of this analysis are discussed in chapter 5.
3.4 Summary
A selection of ten satellite images was chosen to cover the early-mid and late dry season for years 2003-2007. In ERDAS Imagine 9.2 images were subset to the study area in the Coomalie region and underwent unsupervised and then supervised classification methods to better visualise the amount and extent of fires across the site. Accuracy assessment was performed on supervised images from 2006 and 2007 using data gathered in fieldwork. An accuracy level of 83% was determined. Fire patterns were subsequently analysed using the Patch Analyst extension for ArcGIS: Version 4.2 and relevant spatial statistics generated. The results of this are discussed in chapter 5.
Chapter 4
Reproductive Success of Grey-crowned Babblers at Coomalie and The Effect of Group Size on Breeding Success
Chapter outline
This chapter gives an overall summary of the breeding success of the Babbler groups at Coomalie Farm. Results for all groups and those for groups for which complete breeding records from 2003-2007 were available were compared and contrasted to each other and to studies undertaken in southern Australia to determine whether breeding success varies significantly between the northern and southern species. Also in this chapter, Babbler breeding success is investigated with respect to group size. Results are compared with those in southern Australia regarding Babblers and others involving different cooperatively breeding species.

4.1 Introduction
Breeding success in any bird species is by no means assured. Nest predation, climatic conditions, food availability and brood parasitism are significant factors in the determination of nest success or failure (Ford 1989; Sherry and Holmes 1995; Berry 2001). Although approximately 80% of passerine species breed in tropical regions the majority of studies have focussed on temperate species and, subsequently, there are gaps in our knowledge of the natural history of many tropical birds (Stutchbury and Morton 2001; Pierce et al. 2004).

Compared to their northern temperate region counterparts birds of the Southern Hemisphere and tropical regions have small clutch sizes but make many nesting attempts per year; the breeding seasons are longer, the growth rate slower and the parental care of young prolonged. Adult survival is high (Skutch 1966; Ricklefs 1969, 1970). In cooperatively breeding species, such as the Grey-crowned Babbler, it has been speculated that it is the low levels of mortality that have predisposed some species towards this particular breeding system (Arnold and Owens 1998). In turn, the low mortality rate has been linked to areas of reduced environmental fluctuation, lower latitudes and those species with a sedentary lifestyle (Arnold and Owens 1998, 1999). This goes someway to explaining why Australia is home to so many avian species that cooperatively breed.

Consistent with most Australian birds, the Babbler breeding season is relatively long (King 1974; Counsilman 1979; Higgins and Peter 2002). At Coomalie Farm breeding was
recorded from July to December for five years, but it is speculated to begin as early as June and end as late as January or February the following year (Eguchi et al. 2007). This is consistent with the records of the breeding season of the species in south-eastern Australia (Counsilman 1979; Dow and King 1984).

Babblers are known to build separate dormitory (roost) nests and breeding (brood) nests (Counsilman 1979; Higgins and Peter 2002). Several nests, brood and roost, may be located in the same tree or shrub. The nests themselves are large and conspicuous and look like a bundle of twigs (Figure 4.1). There appears to be little attempt to conceal nests with many to be found at the terminal point on outer branches of vegetation. In the Coomalie study site, placement of nests ranged from approximately 1.5 m high (personal observation) to over 6 m (Eguchi et al. 2007) (Figure 4.2). Permanent territories are defended and, although not determined for this project, these have been recorded as ranging from under 2 ha to over 50 Ha (King 1974; Counsilman 1977; Adam and Robinson 1996).

Several studies of this species have been previously undertaken in Australia (King 1974; Counsilman 1979; Dow and King 1984) however, only one thus far has attempted to analyse the breeding biology of Grey-crowned Babblers in the tropical north (Eguchi et al. 2007).

The primary aim of this section of the project was to determine the breeding success of the documented Babbler groups at Coomalie Farm. The mean number of nesting attempts per year and the numbers of fledglings produced for the 5-year study period was investigated. Results of groups that were recorded as nesting every year were compared to those for whom incomplete records existed to see whether there were significant differences between them. These results were then compared to those undertaken in southern Australia.

In the second part of this chapter, breeding success was analysed with respect to group size. Although the phenomenon of cooperative breeding is comparatively rare in the avian world, Australia is home to more cooperatively breeding species than any other continent (Dow 1980; Arnold and Owens 1998; Cockburn 1998). In particular, the Eucalypt woodlands show high numbers of species that use this breeding system and this is often attributed to the low seasonality of this habitat (Brown 1987; Ford et al. 1988).
Group size may vary substantially within and between cooperative breeding species. The size of the group may affect reproductive success, however, there is conflicting evidence regarding this (see: Craig 1980; Ligon 1981; Canestrari et al. 2008 among others). There is some suggestion that whilst an increase in density in non-cooperatively breeding species may be disadvantageous, the opposite may apply to cooperatively breeding species where an increase in group size increases reproductive success (Magrath 2001; Clutton-Brock 2002; Brouwer et al. 2006).

Conversely, many studies have found no effect of group size on reproductive success (Cockburn 1998; Hatchwell 1999); still others noted a variable effect over several years in some species (Koenig and Stacey 1990; Mumme 1992). Another study suggested that an increase in group size may make the group more visible to predators (Courchamp et al. 2000) and still other investigations noted that with increasing group sizes the need for a good quality habitat is paramount (Balda and Brown 1977; Brown 1987). Habitat fragmentation may cause larger groups to suffer lower reproductive success or collapse altogether (Conner and Rudolph 1991; Walters et al. 1999; Cooper et al. 2002).

Emlen and Wrege (1989) suggested seven direct benefits of cooperative breeding; four of those relied on an increase in reproductive success with group size (Magrath 2001). They proposed that increasing group numbers may aid helpers as:

1. Survival may be enhanced by increased group size;
2. Territories may be expanded;
3. Young produced and helpers may form coalitions;
4. Young produced may later become helpers.

As an obligate cooperative breeder, the Grey-crowned Babbler generally requires helpers in addition to the breeding pair to successfully fledge young. Although, across its broad range it most commonly occurs in groups of between four and twelve individuals (Higgins and Peter 2002), the groups recorded at Coomalie were found to be as small as two and no larger than eight. Although the effect of group size on breeding success was analysed by Eguchi et al. (2007) in their study of the Coomalie population of Grey-crowned Babblers, only three years’ worth of breeding data were then included and their study focussed primarily on group composition and inter-group relatedness. In that instance the effect of group size on breeding success was found to be minimal and it was noted that group living was essential: they concluded that unaided pairs
were unable to raise offspring successfully.

In the earlier part of this chapter, it is suggested that five years' worth of data may be the minimum required for an effect to be detectable with regards to this species, thus for this part of the project, although covered previously by Eguchi et al. (2007), I aimed to ascertain whether there was a relationship between group size and breeding success and to determine if there is a relationship between group size and numbers of fledglings produced.
Figure 4.1 Nest of Grey-crowned Babbler at Coomalie Farm, January 2008.
Figure 4.2 Example of location of Grey-crowned Babbler nest at Coomalie Farm.
4.2 Methods
Breeding data collected by the Japanese research team led by Professors Eguchi and Ueda over the years 2003-2007 were used. The research team had undertaken comprehensive identification of individuals by colour banding birds and by extracting DNA (Eguchi et al. 2007). This allowed groups to be recognised with a high degree of certainty over each year of the project. Groups were allocated a unique identification label, e.g. G2, which remained assigned to them regardless of the fluctuation of group numbers, change of locations or a complete breakdown of the group. Intensive searches were made for each group across the study site each year.

The data set included nest coordinates, group size, the order of the nesting attempt, the outcome of the nesting attempt (success or failure) and the number of fledglings that were produced if the nest was successful. The active period of the nest was also included as well as the phase of failure in many cases (building, egg or nestling). The Japanese team checked active nests weekly using a Charged-couple Device (CDD) camera either via a ladder or on the end of a 4 m-long pole. Where the phase of failure was not noted, I determined nest stage using the personal observation of Eguchi et al (2007) that hatching occurred seventeen days after laying and fledging occurred twenty-one days after hatching. This is within the range described by previous studies (King 1974; Counsilman 1979; King 1980). On occasion, the phase of failure was unable to be established and was listed as ‘unknown’.

Three groups recorded a success but had multiple nests and the successful nest was unknown. In this instance, I considered the attempt as one attempt and one nest and omitted the others from calculations. This reduced the number of total nests considered from 146 to 140.

Nests were analysed as a whole set and then those groups for whom breeding data were available for every year between 2003 and 2007 inclusive, hereafter known as ‘Every Year Nesters’ (EYN), were analysed separately. This was done to investigate whether these particular groups had any characteristics that may account for their continuing stability.

Analysis of Variance (ANOVA) was used to investigate the impact of year on nesting attempts and fledglings produced.
To determine an effect of group size on breeding success data were again analysed as a complete set (all nests included) and then EYN were analysed separately.

Spearman rank correlation analysis was used to determine whether the measurement variables of group size and nesting success covaried i.e. as group size increased, nesting success either increased or decreased. This analysis was also used to subsequently investigate whether there was an association between group size and fledgling numbers; all nests, successful and unsuccessful were used in the analysis. In both cases, individual group names are the nominal variable.

To determine whether there was an effect of year on group size, a Kruskal-Wallis analysis was performed as the data did not meet the normality assumption required for ANOVA. Group size was the measurement variable and year the nominal variable.

**4.3 Results**

**4.3.1 Breeding success**

Using records for which the beginning of breeding was noted, the majority of nesting commenced in September (28.6%) followed by October (24.1%).

Over the five-year (2003-2007) study, of the 140 recorded brood nests (including one nest used for two successive breeding attempts in one season) only 31 (22%) were successful i.e. at least one fledgling was produced. This gave a mean of 6.2 (SD 3.63, n=5) successful nests per year. No groups were recorded as having succeeded in each year of the study period and only one (H44) had success four years from the five years that they were recorded as breeding.

The highest proportion of successful nests was in 2004 with 0.42; the lowest was in 2007 with 0.09 (Figure 4.3). This variation between years in successful nests was highly significant (chi-square=19.4, df=8, p=0.01).

The number of groups recorded as breeding each year showed a decline although there was an increase of one group between 2005 and 2006. For EYN the proportion of successful to failed nests declined from 2003 to 2005 with no successes recorded in 2007 (Figure 4.4).

**4.3.2 Nesting attempts**

Of twenty-seven groups with breeding results recorded, there were nine groups that
were recorded as attempting to breed each year from 2003-2007. These contributed 80 nests to the overall total, 14 of which were successful; a success rate of 18% within this subgroup.

The average number of breeding attempts per group was highest in 2006 but lowest the previous year (Figure 4.5). An average of 1.6 attempts per group per year for the 5-year study period was determined. This was slightly lower than that for those groups that nested every year which had an average of 1.8 attempts per group per year over 5 years. As with the overall trend of nesting attempts, 2006 was shown to have the greatest number of nesting attempts per group with 2005 having the least (Figure 4.6). Four groups had two or more nesting attempts per year, with one group (G51) having a relatively high success rate of 25%. A ANOVA demonstrated that the average number of breeding attempts varied significantly from year to year (F=4.3, df=4.81, p=0.003). Further analysis using the Tukey-Kramer test determined that the mean number of breeding attempts between years 2004 and 2006, and 2005 and 2006 were significantly different (p<0.05).

At Coomalie, eight groups bred more than once per year in any one of the five years; however only two groups attempted re-nesting after a success: Group G20 in 2003 and G70 in 2005. For both, the following attempt was unsuccessful. Several groups attempted further nesting after having nestlings or eggs fail in prior attempts with seven successfully raising fledglings at the following attempt (Table 4.1).
Table 4.1 Groups that were successful after prior failed nesting attempts in the same year.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>YEAR</th>
<th>NUMBER OF FAILURES PRIOR TO SUCCESS</th>
<th>TOTAL NUMBER OF NESTING ATTEMPTS</th>
<th>MONTH OF SUCCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>G40</td>
<td>2003</td>
<td>1</td>
<td>2</td>
<td>Oct</td>
</tr>
<tr>
<td>H44</td>
<td>2003</td>
<td>1</td>
<td>2</td>
<td>Nov</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>1</td>
<td>2</td>
<td>Unknown</td>
</tr>
<tr>
<td>H6</td>
<td>2003</td>
<td>2</td>
<td>3</td>
<td>Nov</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>1</td>
<td>2</td>
<td>Sept</td>
</tr>
<tr>
<td>G13</td>
<td>2004</td>
<td>1</td>
<td>2</td>
<td>Oct</td>
</tr>
<tr>
<td>H28</td>
<td>2004</td>
<td>1</td>
<td>2</td>
<td>Oct</td>
</tr>
<tr>
<td>G75</td>
<td>2006</td>
<td>2</td>
<td>3</td>
<td>Dec</td>
</tr>
<tr>
<td>G78</td>
<td>2007</td>
<td>1</td>
<td>2</td>
<td>Oct</td>
</tr>
</tbody>
</table>
Figure 4.3 Proportion of successful and failed nests per year (n=number of nesting attempts).

Figure 4.4 Proportion of successful and failed nests per year for those groups who were recorded as nesting every year 2003-2007 (n=number of nesting attempts; 9 groups).
Figure 4.5 Mean number of all nesting attempts per group per year; error bars represent the standard error of the mean.

Figure 4.6 Mean number of nesting attempts per group per year for those groups that were recorded as nesting every year 2003-2007 (9 groups); error bars represent the standard error of the mean.
4.3.3  Fledglings

Forty-seven fledglings were recorded overall, with sixteen successful nests producing one fledgling; fourteen nests producing two fledglings and one nest producing three fledglings. The greatest number of fledglings produced by a group over the study period was six (groups H44 and G13).

Overall and for those groups recorded as nesting every year, 2004 had the highest mean number of fledglings per group and per nest. The lowest mean number of fledglings per group and per nest occurred in 2007 with no fledglings recorded at all for EYN (Figure 4.7 and Figure 4.8).

As data were not normally distributed, a Kruskal-Wallis test was used to determine whether there was an impact of year on the number of fledglings produced in both instances.

When all groups were considered, year was shown to have no significant effect on the number of fledglings produced per group (H=7.72, df=4, p=0.10); however, when the analysis was restricted to EYN groups, there was a significant difference between years in the number of fledglings per group (F=12.89, df=4, p=0.01).
Figure 4.7 Mean number of fledglings per group and per nest for all groups; error bars represent the standard error of the mean.

Figure 4.8 Mean number of fledglings per group and per nest for those groups recorded as nesting every year 2003-2007; error bars represent the standard error of the mean.
4.3.4 Group size and breeding success

Twenty-seven groups had breeding results recorded. Group sizes ranged from 2 to 8 individuals; mean group sizes are shown in Table 4.2 and a comparison of all groups and EYN is shown in Figure 4.9.

Table 4.2 Mean group sizes for all groups and EYN over the period of study

| YEAR | ALL GROUPS | | EYN | |
|------|------------|----------------|------|----------------|----------------|------|----------------|----------------|------|----------------|----------------|
|      | Mean group size | Standard deviation | Number of groups | Mean group size | Standard deviation | Number of groups | |
| 2003 | 3.75 | 1.33 | 20 | 4.0 | 1.22 | 9 | |
| 2004 | 4.44 | 1.65 | 18 | 5.0 | 1.66 | 9 | |
| 2005 | 4.06 | 1.52 | 17 | 4.33 | 1.5 | 9 | |
| 2006 | 3.89 | 1.71 | 18 | 3.89 | 1.62 | 9 | |
| 2007 | 3.69 | 1.49 | 13 | 3.89 | 1.62 | 9 | |

Mean group size across the five year study period was 3.98 (1.53 SD, n=86) for all groups and 4.22 (SD 1.52, n=45) for EYN.

Variation in group sizes for the recorded groups is shown in Table 4.3 along with the indication of whether a group was successful, that is, the group raised at least one fledgling, and years when the group was not recorded due to being unable to be found.
Table 4.3 Variation in group sizes over the study period. Yellow shaded cells are those that recorded a success in that year; NR = no record for that year.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>G13</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>G40</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>G50</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>NR</td>
</tr>
<tr>
<td>G67</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>NR</td>
</tr>
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<tr>
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<td>6</td>
<td>2</td>
<td>NR</td>
</tr>
<tr>
<td>H6</td>
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</tr>
<tr>
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<td>6</td>
<td>NR</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>H38</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
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<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>G72</td>
<td>NR</td>
<td>2</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>G74</td>
<td>NR</td>
<td>3</td>
<td>3</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>G76</td>
<td>NR</td>
<td>NR</td>
<td>2</td>
<td>NR</td>
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<tr>
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<td>NR</td>
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<td>NR</td>
</tr>
<tr>
<td>G78</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>G79</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>2</td>
</tr>
</tbody>
</table>

A Kruskal-Wallis test was carried out on both EYN and all groups to determine whether there was a significant effect of year on group size. In both cases, there was no significant variation between years in groups size (all groups: $H=2.84$, df=4, $p=0.59$; EYN: $H=3.93$, df=4, $p=0.42$).
Figure 4.9 Mean group sizes 2003-2007.

Figure 4.10 Percentages of successful nests in relation to group size over the study period 2003-2007 for all groups; n=number of groups.
Considering all nests with known fates, group sizes of 6 and 8 birds had the highest success rate of 50%, although the latter concerned only one group. Groups of only two birds (pairs) had the lowest success rate of 5.6%. The proportion of successful nests increased steadily with group size up to that of six birds and then declined sharply at seven, although again the sample size for the latter was low (Figure 4.10).

Spearman rank correlation analysis on group size and the number of successes recorded showed that there was a significant trend towards increasing breeding success with increasing group size for all groups and EYN (Spearman’s rho=0.26, p=0.002 and Spearman’s rho=0.25, p=0.03 respectively).

### 4.3.5 Group size and fledglings

The smallest group size to have a successful nest was a single pair in 2006. Two fledglings were recorded. The largest group to record a success was that of a flock of eight birds in 2004 (G13); three young were fledged. Spearman rank correlation analysis of all nests found a significant relationship between increasing group size and the number of fledglings produced for both EYN (Spearman’s rho=0.24, p=0.03) and all groups (Spearman’s rho=0.27, p=0.001). However, the same analysis performed on fledglings per bird for successful groups found that the number of fledglings produced per bird decreased significantly with increasing group size (Spearman’s rho=-0.49, p=0.005) (Figure 4.11). It was not uncommon to find that the mean number of fledglings per bird varied between groups of the same size.
Figure 4.11 Number of fledglings per bird for each group size of successful nests; note: n=number of successful nests.
4.4 Discussion

4.4.1 Overall breeding success
The overall success rate of Babblers at Coomalie Farm over the five-year study period, 22% of all nesting attempts, is somewhat at the low end of a large range when compared with studies conducted in temperate Australia where success rates for Grey-crowned Babblers range from 20-68.8% (Counsilman 1979; Higgins and Peter 2002). Counsilman (1979) attributed the low success rate of Grey-crowned Babblers at Dyer’s Lagoon in south-eastern Queensland primarily to predation (25% of nest failures), both by native and introduced predators, and weather conditions (also 25% of nest failures). Eguchi et al. (2007) recorded that 60% of nest failures of Babbler groups at Coomalie Farm were caused by predation but made no mention of weather conditions as a factor. As the failure due to predation at Coomalie was recorded at more than twice that of Dyer’s Lagoon, it would seem that increased levels of predation more than account for the low success rate.

It could be argued that the success rate of the tropical Babblers should be significantly higher than those in temperate Australia. Babblers in the southern part of the country suffer from considerable habitat loss or modification (Adam and Robinson 1996; Department of Sustainability and Environment 2009) whereas those found in the tropical savannas have the luxury of a largely unfragmented home range. The impact of introduced species is also greater for those Babblers in the temperate part of Australia with livestock such as cattle being at much lower densities in the northern savanna region than in south-eastern Australia (Australian Bureau of Statistics 2007). However, it may be that this same unfragmented habitat and lesser pressures of introduced species may also be aiding those species that prey upon Babbler nests.

The reduced seasonality and greater predator diversity in tropical areas is considered by some to make food availability a limiting factor in both breeding success and the number of nesting attempts made (Ashmole 1963; Ricklefs 1980; Thiollay 1988). Eguchi et al recorded 29% of nest failures to have been caused by either egg abandonment or chick starvation suggesting that fluctuations in food resources may have a significant influence on breeding success, particularly as nest predation and food limitation have been found to strongly interact to influence behavioural traits of breeding birds (Martin 1992, 1995). A further consideration is that due to the generally favourable climatic
conditions in the tropical zone, bird populations may reach close to a maximum carrying
capacity of a habitat thus making food limitations a real constraint on breeding success;
there literally may not be enough food (Ashmole 1963; Ricklefs 1980; Martin 1996).
Robinson et al. (2000) in a study comparing North American bird species to tropical
Panamanian species found that the nesting success of tropical species was more than
20% lower than similar species in the temperate region. However, they did concede
that in some years the nesting success of tropical birds was near or equal to their
temperate counterparts.

4.4.2 Nesting attempts
It is widely considered that tropical birds have more broods per year and higher re-
nesting rates than their temperate counterparts due to their extended breeding seasons
and higher rates of nest predation (Ricklefs 1969; Skutch 1985; Yom-Tov 1987; Rowley et
al. 1991); however, a number of studies have indicated that there may not be as much a
difference between tropical and temperate species as commonly thought (Martin
1996). Regardless, it has been noted that many Australian birds commonly have two or
three broods per year and may re-nest several times (Major 1991; Rowley and Russell
1993; Franklin et al. 1995).

The number of nesting attempts made by the groups at Coomalie Farm was lower than
other studies (e.g. Councilman 1979) by more than half. Multibroodedness was
displayed in the Coomalie Babbler groups but not to the same extent as in other
studies, only 8 groups out of the 27, and only two of those attempted nesting again
after a success. Blackmore and Heinsohn (2007) recorded 65% of the groups they
studied in NSW as re-nesting in a season with 52% following a success.

Foster (1974) has stated that most tropical birds will re-nest following a failed nesting
attempt and may continue to do so until the nesting succeeds or the breeding season
ends. However, compared to temperate birds, tropical species take longer to incubate
eggs and rear independent young (Ricklefs 1969) therefore, depending on when in the
breeding season the prior nest failed, it may not be possible for re-nesting to occur.

As mentioned previously, food limitation may also be a major factor in determining
whether re-nesting occurs. Thiollay (1988) concluded in a study on comparative
insectivorous birds in tropical and temperate habitats that, on average, food resources
may be more abundant, evenly distributed and richer in the temperate zone than the
tropics. It was then proposed that this would be likely to limit the reproductive rate of tropical insectivores. Likewise König and Gwinner (1995) demonstrated experimentally that singlebroodedness in Stonechats (Saxicola torqueta axillaris) in tropical parts of Africa was most likely as a result of food limitation as this species was multibrooded in the northern temperate zone. Skutch (1949 and 1985) disagrees arguing that food is not limiting in tropical species as parent birds have were known to have been able to successfully rear young when:

a. The brood size was experimentally increased;

b. Only one parent was raising young in certain species; and

c. Diet is significantly different between species.

If one accepts Skutch’s reasoning it could be suggested that due to the lower environmental pressures (abundant, unfragmented habitat; fewer competing introduced species etc.) on the northern tropical Babblers the impetus to produce multiple broods is not there. A constant, reliable food supply and the maintenance of habitat integrity resulting in greater adult survival may reduce the biological imperative to re-nest after a success.

4.4.3 Fledglings

The fact that an effect of year on fledgling numbers was seen with EYN is intriguing. It strongly suggests that some years may be considered ‘good’ and others ‘bad’ for fledgling survival. 2004 was the best year for fledglings, both for EYN and overall; obviously environmental conditions were prime for survival of young. Blackmore and Heinsohn (2007) suggested helper birds are more beneficial for successful reproduction in lean years rather than those years that are considered ‘good’. The issue of group size will be addressed in a later section.

That the impact of year was not seen when analysing all groups implies that a minimum of five years’ worth of records is required when investigating this aspect of Babbler breeding ecology. Incomplete breeding records (those with less than five year records) outnumbered EYN two to one and this may have masked the effect.

4.4.4 Group size and breeding success

It has been claimed frequently that increasing group size in cooperatively breeding birds
leads to an increase in breeding success (Woolfenden 1975; Brown 1987; Clutton-Brock 2002). However, there is relatively little experimental evidence to support this assertion (Magrath and Yezerinac 1997; Magrath 2001) and there is some dispute as to whether breeding success is enhanced or hindered by increasing group numbers (Magrath 2001; Bednekoff and Lima 2004).

It warrants bearing in mind that measures of reproductive success may be open to contrasting interpretation depending on the perspective taken, in this case, group size versus individual birds. It is important to know what factors may be contributing to differences in reproductive success within, and between, populations. Again, the majority of research undertaken on this topic is focussed on temperate species, most commonly in the northern hemisphere, and this can make comparative studies difficult (Murray 2000). Research on Hall’s Babbler (Pomatostomus halli) in southern Queensland found that group size was strongly correlated with the quality of the habitat Balda and Brown (1977) and Walters et al. (1999) similarly found that the average group size of Brown Treecreepers (Climacteris picumnus) in New South Wales was less in fragmented habitats than those in unfragmented. One of the few studies carried out in the tropical zone, that of a species living in the Seychelles, Brouwer et al. (2006), found that there was a lower survival probability for birds in larger groups than those in smaller; however this was not found to be connected to the availability of food resources.

The Grey-crowned Babbler is one of the few species in which an increase in group size has been experimentally shown to lead to greater breeding success on a per-group basis (Brown et al. 1978; Brown and Brown 1981). The results of this study concur, in the main, with related studies; a slightly unusual result for this particular population being recorded in that a single pair was found to have successfully fledged two young. Eguchi et al. (2007) in their earlier study found that single pairs at Coomalie did not experience breeding success; however Blackmore and Heinsohn (2007) studying a Grey-crowned Babbler population in New South Wales found that half of the breeding attempts by single pair birds fledged successfully.

The proportion of successful nests for the Coomalie Babbler groups increased with increasing group size up to groups of 6 individuals; at 7 there was a decline. Initially, this result seems anomalous when compared to other studies; however, King (1974)
noted that, whilst not directly hindering breeding success, larger groups appeared less efficient at nest building than their smaller counterparts. The increase in the proportion of successful nests again at group size of 8 is difficult to take at face-value as only one group was recorded at this size. There was no significant difference in group sizes between years. This allowed results to be pooled across years in subsequent analyses. Predation and interference by a co-existing cooperatively breeding species, the Blue-faced Honeyeater *Entomyzon cyanotis*, were noted by the Japanese research team led by Dr. Eguchi as the primary causes of nesting failure in the Babbler groups at Coomalie Farm (unpublished data). As the group sizes that were most successful were those consisting of 6 (overall) or 7 (EYN) birds it may be speculated that the notion of larger groups being less successful as they attract more predators to the nest site does not apply in this instance. What is more likely is that larger groups have greater numbers to defend nests whereas with smaller groups provisioning sessions may leave nests unguarded and vulnerable to predation. However, few studies have conclusively proven a link between the number of helper birds and nest predation rates in cooperatively breeding species (Boland 1998). Poiani and Pagel (1997) suggest that rather than increasing group size deterring predators, cooperatively breeding birds develop anti-predator strategies similar to those found in birds that do not use this breeding system. Due to the retrospective nature of the study it is unknown as to whether the Coomalie Babblers displayed anti-predator tactics but based known typical helper behaviour in communally breeding birds (Brown 1978), it would not be unreasonable to assume these behaviours occur.

### 4.4.5 Group size and fledglings

Like Nias and Ford (1992) in their study on Superb Fairy-wrens, another cooperatively breeding passerine, the number of fledglings per bird for successful groups was found to decrease with increasing group size. Even though the habitat at Coomalie Farm is considerably less disturbed than the fragmented Babbler habitats in southern Australia there may still be an optimal group size to habitat quality ratio required to raise greater numbers of fledglings; it may be that there is a link between individual fitness and the number of offspring successfully reared.

Studies of Babblers in southern Australia have shown conflicting results. Blackmore and Heinsohn (2007) found that group size had no effect on the number fledglings
produced, whereas Brown and Brown (1981) discovered a positive correlation between fledgling numbers and the size of the group during the breeding season. Brown and Balda (1977) discovered a positive correlation between habitat quality and group sizes in Hall’s Babblers but were sceptical as to whether this translated into a positive effect on breeding success and fledgling numbers.

In a tropical area comparison, Rabenold (1984), in a study on tropical wrens in savannas in Venezuela, found a general trend of increasing numbers of fledglings with increasing numbers of helpers. Another study on a cooperatively breeding species in a savanna habitat, this time in Africa (Corvas and du Plessis 2005) also determined increasing group size to increase the number of young fledged.

For this study area Eguchi et al. (2007) reported that unaided pairs did not successfully raise young. However, one single pair group raised two fledglings at this site in 2004. This low success rate for unaided pairs contrasts noticeably with a study by Blackmore and Heinsohn (2007) that noted that 50% of the unassisted pairs they studied in New South Wales were able to fledge young. Causes of nest or fledgling failure were not mentioned nor did they document levels of potential nest predators.

Ultimately, whilst it is tempting to imply that reproductive success is improved by increasing group size, caution when interpreting results must be exercised. Whether group size is a cause or effect of reproductive success is difficult to ascertain; other variables such as the fitness of the breeding pair, predation pressures and habitat quality need to be taken into account. For the Babbler groups at Coomalie Farm, the last variable mentioned may be linked with fire.

4.5 Summary

In summary, despite inhabiting a largely undisturbed habitat, Babbler breeding success rates at Coomalie are comparable to those of southern Australia, albeit at the lower end of recorded rates. Although slightly more likely to fledge just one youngster, successful nests commonly saw two young fledged (52% and 45% of successful nests respectively). With groups that had complete 5-year records there was a significant difference between years in fledgling numbers that wasn’t seen in groups with incomplete records, however too many environmental variables were unknown to definitely state why some
years are better than others. Whilst some groups were multibrooded this was not recorded in the same numbers as in studies in southern Australia. The breeding season spanned the same months as in southern Australia, June-July to January-February, however, the majority of breeding occurred in September-October, the late dry season.

Grey-crowned Babblers are commonly found in groups of between 4 to 12 individuals. At Coomalie farm, the Babbler group sizes ranged from 2 to 8 birds. The average group sizes varied little between years.

Groups of 6 and 8 birds were the most successful whereas groups comprising a single pair were least successful.

There was a positive correlation between group size and nest success and number of fledglings produced in agreement with studies of the species in southern Australia. However, when expressed in terms of reproductive output per individual, there was a significant negative correlation between group size and number of fledglings produced.
Chapter 5
Analysis of the Effect of Fire on Breeding Success
Chapter outline

Breeding success of the Coomalie Farm Babbler groups is analysed with respect to the fire regimes of the area. The patterns of fire across the area are investigated and the impact of the timing of fire is studied to determine the effect, if any, on Babbler reproductive success. Group size is singled out specifically to see if short-term fire history is ultimately having an impact on subsequent breeding attempts.

5.1 Introduction

Australia is recognised as the most flammable country in the world (Bowman 2003) and the most frequent and extensive fires occur across northern Australia (Dyer et al. 2001b; Williams and Cook 2001a). In this part of Australia, fire is a prominent tool for land and resource management, first effectively used by the Aboriginal people some 40000 years ago and still used today by land managers (Andersen and McKaige 1998). Fire regimes in the Top End have been altered from the traditional indigenous method of year-round mosaic burning to frequent, often extensive fires to maximise pasture growth in many areas of the savannas (Williams and Cook 2001a; Gill et al. 2003). Pre-emptive or prescribed burning occurs during the early dry season (April/May) to help mitigate the more severe effects of late dry season fires (Gill et al. 2003).

Concerns about the effect of inappropriate fire regimes on Australian bird populations were raised as early as 1924 (Ashby 1924) and continue up to the present day (Pyke et al. 1995; Woinarski et al. 1999; Olsen and Weston 2005). Although there is considerable overseas literature concerning the effect of fire on the reproductive success of birds (Kochert et al. 1999; Cahill and Walker 2000; Moreira et al. 2003 among others) few such studies have been conducted in Australia. Those that have tend to be focussed more on the effects on breeding after single or irregular fire events rather than repeated fires or an established fire regime (e.g. Brooker and Rowley 1991; Russell and Rowley 1993; Loyn 1997).

Across Australia, the habitat of the Grey-crowned Babbler is described as open forests and woodlands in the south and open forests and savanna woodlands in the north (Higgins and Peter 2002; Blackmore and Heinsohn 2007). Babblers in the north have
their habitats more or less intact unlike the heavy fragmentation of Babbler habitats in the south. It has been documented that in Victoria, Babblers now need their habitat to consist of five essential components (Davidson and Robinson 1992; Robinson 1993, 1994):

1. Open forest or woodland with fertile soils;
2. Large numbers of mature Eucalypt trees or Cypress Pines;
3. More trees than at sites that do not support Babblers;
4. Understorey of shrubs and saplings;
5. Ground layer with minimal grass cover yet plentiful litter.

If any of these elements are missing, Babblers will not inhabit the site and have been found to vacate areas where even one of these factors is removed (Davidson and Robinson 1992; Robinson 1993, 1994)

Adam and Robinson (1996) discovered that fuel reduction burning in northern Victoria was having a significant negative impact on Babblers by removing understorey vegetation. In contrast to this, studies in northern Australia suggest that Grey-crowned Babblers have developed a tolerance to fires and may even prefer habitats that are annually burnt (Woinarski 1990; Woinarski et al. 2004; Legge et al. 2008). The breeding season of Grey-crowned Babblers in the Top End of the Northern Territory overlaps in part with the fire season. It is, therefore, reasonable to assume that fire may have some impact, direct or indirect, on the outcome of nesting. Approximately 60% of the Coomalie region on average is burnt annually with Eucalypt woodlands being the habitat that suffers the highest proportion of burning (Price and Baker 2003).

At Coomalie Farm controlled burning to provide fire breaks occurs in the early dry season with wildfires affecting the area from the mid-dry to the late-dry season. On occasion fires will break out during the following wet season.

This part of the project aimed to answer several questions that related back to the primary aims:

1. Is there a variation in breeding outcomes between nests that are situated in burnt areas and those that are situated in unburnt areas?
2. Do breeding outcomes vary significantly from year to year depending on the fire history of the nest site?
3. Does the timing of fire within a year have an effect on breeding results?
4. Does fire incidence in the preceding year affect group size and, thus, breeding success?

5.2 Methods
The data set of Babbler breeding results utilised in chapters 5 and 6 was again used here but subjected in this instance to a combination of statistical and spatial analyses.

The impact of fire upon Babblers was initially considered by simply categorising whether the area immediately around the nest site had experienced fire in that year, with fire incidence determined via the GIS using a satellite image obtained for the early-mid dry season and late dry season. Due to small sample sizes the success or failure of nesting in burnt and unburnt areas (according to aforementioned images) over the five-year period was compared using Fisher’s exact test. This test determines non-random associations between two nominal variables and calculates the deviance from the null hypothesis that the relative proportions of one variable are independent of the other. Data were arranged in a 2×2 table using the nominal variables ‘Breeding outcome’ (success or failure) and ‘Fire history of site’ (burnt or unburnt). To determine whether the fire history of the nest site (burnt or unburnt) affected breeding outcomes from year to year, the Cochran-Mantel-Haenszel test was applied to nest results as the third nominal variable of ‘year’ had been included. This test is used for repeated tests of independence where there are three nominal variables; two of which are tested for independence with the third identifying the repeats. The null hypothesis is that the two nominal variables tested in repetition are independent of one another. In essence, the data used in the 2×2 table for Fisher’s exact test were separated out into their corresponding years and re-analysed.

To assess the impact of the timing of fire within a year on the success or failure of nests, fire maps were reclassified to give a more discriminating division of fire categories. The reclassification of fire maps gave a finer distinction between fire categories resulting in: Early-Mid dry season fires (May-July); Late dry season fires (Aug-Oct); Unburnt and Bare Earth. Some areas were burnt both in the early and late dry as determined by the reclassification process. Because of this more refined division of fire status, one of the successful nest outcomes had to be omitted as it was unknown exactly which of two
nests had provided the result and the two individual nest sites had different fire
statuses, and one nest recorded as a failure was removed from consideration as cloud
shadow resulted in the area being recorded as ‘unclassified’. Fisher’s exact test was
used to analyse nest data in the resulting categories.

When attempting to determine whether the incidence of fire has an impact on Babbler
breeding success there were a number of constraints on the data:

1. As there are only two fire maps per year often there was uncertainty about the
timing of fire relative to breeding;
2. Only the immediate location of the nest site was taken into consideration when
assigning a fire status to the site;
3. Some of the breeding periods recorded are imprecise;
4. Nest outcome may, in many instances, be overwhelmingly due to factors other than
fire.

Fire patterns across the study site were investigated using the Patch Analyst extension
for ArcGIS: Version 4.2 (Rempel et al. 2008), a programme designed for ascertaining
landscape structure (as discussed in chapter 3).

To investigate the effect of fire on group size and, therefore, breeding success, a short-
term fire history of Babbler nesting sites was developed. Data were organised into
nests by group by year, converted into shapefiles using ArcCatalog and imported into
the database. Those groups recorded as EYN were used as these cover the entire 5-year
study period and, thus, give a more complete picture of breeding success and fire
history. Group sizes for years 2004-2007 were used. The group sizes for 2003 were
omitted as the fire data for 2002 consisted of only one fire map.

Circular buffer zones were created around each set of nests at 10, 20 and 50ha area to
simulate potential territory sizes (King 1974; Counsilman 1977; Adam and Robinson
1996). These were then layered onto the previous year’s fire map images (i.e. 2006
nesting data were added to the 2005 fire maps) to determine the short-term fire history
for the sites. The GIS data were separated into early-mid dry and late dry categories
and the burned proportion of each of the three territory sizes around the nest site was
calculated.

Data were analysed using the ‘R’ system for statistical analyses and graphics (R
Development Core Team 2008). The analysis was carried out for each territory size on the combined total proportion of territory burnt and individually for early-mid and late dry season. A Generalised Linear Mixed Model (GLMM) was run in R with ‘Group’ as a random effect (that is, it may cause some variation but is not of direct interest) and fire proportion as a fixed effect. Generalised linear modelling was chosen as GLMs are flexible enough to include a wide range of common situations, but at the same time allow most of the familiar ideas of normal linear regression to carry over (Guisan et al. 2002). The mixed model method specifically was selected as it is an extension to GLMs that allow for random effects (in this case group size) along with fixed effects (fire) (Bolker et al. 2009). This was used to relate the fire history in any year to the following year’s group size and, thus (see Chapter 4), breeding success. The decision to use group size as a measure of breeding success was arrived at due to the nature of the data available. To directly link fire to breeding success, multiple breeding results of the site would be needed over repeated times; unfortunately, this was not part of the data sets obtained. Analysis using other variables was unsuitable as there was too much correlation in the data and covariates.

5.3 Results

5.3.1 Patterns of fire across the study site

The extent of the study site burnt each year ranged from a minimum of 36% in the early-mid dry of 2007 to a maximum of 76% in the late dry of the same year (Table 5.1). Although it was expected that the majority of area presenting as burnt during the classification processes would be in the image for the early-mid dry, as subsequent fires may not have the same fuel loads available, three out of the five years showed a larger percentage of the study site being burnt in the late dry image. The most likely explanation for this is the duration and rainfall of the preceding wet season. Although fuel loads may have been higher in the early dry, the amount and timing of rainfall may have delayed fuel curing.

Analysis of fire maps using Patch Analyst 4.2 showed little variation of fire patterning across the study site (Table 5.2). Due to the fact that only two satellite images were available for each year, whether burnt patches occurred due to a single fire event or
several individual fires is unknown. As noted in Chapter 4, no early fire category was returned for the late dry image for 2004 therefore no spatial statistics were generated for this category in the late dry 2004 analysis. That the Mean Shape Index (MSI) in all cases was greater than 1 indicates that patches are irregular (complex) as opposed to circular or rectangular. ANOVA performed on Mean Nearest Neighbour (MNN; the average distance between two patches of the same type) results showed no significance between fire categories, year or time of fire (early-mid or late dry) (F=0.90, df=5, p=0.50). Very little variation was seen in Mean Patch Size (MPS) although the late dry image for recent fire in 2007 had the largest MPS of all images (0.13 km²). This corresponds with data in Table 5.1 indicating that in the late dry image for 2007, 76% of the total study area was recorded as having been burnt.

5.3.2 The effect of fire on breeding success
Of the 30 successful nests, 27 were located at a site that was burned at least once in a given year and three were in areas that registered as unburnt in a given year on the fire maps used in analysis. Across years, the minimum percentage of successful nests that were in areas that experienced fire during the fire season was 78%. The proportion of nests that failed or succeeded in burnt and unburnt areas is shown in Figure 5.1.

The history of the site (burned or unburned) had no significant effect on the fate of the nest (success or failure), with all years combined (Fisher’s exact test, df = 1, p = 0.60) or with years separated (Cochran-Mantel-Haenszel test, Chi-square = 0.0014; df = 1; p = 0.97).
Table 5.1 Percentage of burnt and unburnt areas as extracted from Patch Analyst results

<table>
<thead>
<tr>
<th>YEAR</th>
<th>% PATCHES EXPERIENCING SOME FIRE</th>
<th>% UNBURNT PATCHES</th>
<th>% TOTAL AREA BURNT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FIRE IMAGE</td>
<td>FIRE IMAGE</td>
<td>FIRE IMAGE</td>
</tr>
<tr>
<td></td>
<td>Early-Mid Dry</td>
<td>Late Dry</td>
<td>Early-Mid Dry</td>
</tr>
<tr>
<td>2003</td>
<td>65</td>
<td>45</td>
<td>23</td>
</tr>
<tr>
<td>2004</td>
<td>51</td>
<td>36</td>
<td>24</td>
</tr>
<tr>
<td>2005</td>
<td>59</td>
<td>64</td>
<td>27</td>
</tr>
<tr>
<td>2006</td>
<td>61</td>
<td>70</td>
<td>29</td>
</tr>
<tr>
<td>2007</td>
<td>69</td>
<td>62</td>
<td>22</td>
</tr>
</tbody>
</table>

The preceding table omits patches that were classified as bare earth or unclassified, as a determination of fire in these instances was impossible. The percentage of total area burnt refers to the total amount of the study site registering as burnt when the specific image was taken.
Table 5.2 Results of Patch Analyst analysis of fire maps; note: EMD=Early-mid dry fire map, LD=Late dry fire map, UN=Unburnt, EF=Early Fire, RF=Recent Fire.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fire Category</th>
<th>Mean Nearest Neighbour (km)</th>
<th>Mean Shape Index</th>
<th>Total Edge (km)</th>
<th>Mean Patch Size (km²)</th>
<th>Number of Patches</th>
<th>Class Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>EMD</td>
<td>LD</td>
<td>EMD</td>
<td>LD</td>
<td>EMD</td>
<td>LD</td>
</tr>
<tr>
<td>2003</td>
<td>UN</td>
<td>0.42</td>
<td>0.51</td>
<td>1.41</td>
<td>1.44</td>
<td>0.23</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.40</td>
<td>0.50</td>
<td>1.38</td>
<td>1.41</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>0.55</td>
<td>0.70</td>
<td>1.25</td>
<td>1.26</td>
<td>0.15</td>
<td>0.11</td>
</tr>
<tr>
<td>2004</td>
<td>UN</td>
<td>0.54</td>
<td>0.40</td>
<td>1.38</td>
<td>1.31</td>
<td>0.18</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.41</td>
<td>0.00</td>
<td>1.34</td>
<td>0.00</td>
<td>0.26</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>0.47</td>
<td>0.41</td>
<td>1.32</td>
<td>1.37</td>
<td>0.20</td>
<td>0.26</td>
</tr>
<tr>
<td>2005</td>
<td>UN</td>
<td>0.45</td>
<td>0.36</td>
<td>1.32</td>
<td>1.32</td>
<td>0.23</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.33</td>
<td>0.38</td>
<td>1.34</td>
<td>1.39</td>
<td>0.36</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>0.50</td>
<td>0.81</td>
<td>1.28</td>
<td>1.26</td>
<td>0.16</td>
<td>0.11</td>
</tr>
<tr>
<td>2006</td>
<td>UN</td>
<td>0.37</td>
<td>0.50</td>
<td>1.33</td>
<td>1.30</td>
<td>0.23</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.47</td>
<td>0.51</td>
<td>1.30</td>
<td>1.33</td>
<td>0.22</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>0.62</td>
<td>0.40</td>
<td>1.29</td>
<td>1.35</td>
<td>0.12</td>
<td>0.28</td>
</tr>
<tr>
<td>2007</td>
<td>UN</td>
<td>0.36</td>
<td>0.66</td>
<td>1.35</td>
<td>1.31</td>
<td>0.24</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>0.44</td>
<td>0.70</td>
<td>1.33</td>
<td>1.39</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>0.61</td>
<td>0.39</td>
<td>1.26</td>
<td>1.33</td>
<td>0.12</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Figure 5.1 Nest results in burnt or unburnt sites for each year 2003-2007; n=number of nests.
5.3.2.1 Timing of fire
The highest percentage of successful nests was in areas that experienced both early-mid and late dry season fires in the current year (Table 5.3); however, overall there was no significant relationship between fire category and nest success (Fisher’s exact test, df=3, p=0.25).

Table 5.3 Summary of nesting results for each fire category.

<table>
<thead>
<tr>
<th>Fire category</th>
<th>Nesting outcome</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>% Successful</td>
<td></td>
</tr>
<tr>
<td>Early-mid dry</td>
<td>16</td>
<td>47</td>
<td>25.4</td>
<td></td>
</tr>
<tr>
<td>Late dry</td>
<td>3</td>
<td>25</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>Early-mid &amp; late dry</td>
<td>7</td>
<td>15</td>
<td>31.8</td>
<td></td>
</tr>
<tr>
<td>No fire</td>
<td>4</td>
<td>20</td>
<td>16.7</td>
<td></td>
</tr>
</tbody>
</table>

Results, using records for which the timing of fire could be reasonably assessed and the nest fate was known, are shown in Table 5.4.

Table 5.4 Breeding results relative to incidence of fire.

<table>
<thead>
<tr>
<th>Fire incidence</th>
<th>Nesting outcome</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsuccessful</td>
<td>Successful</td>
<td>Number of fledglings</td>
<td>Total nests considered</td>
<td>% Successful nests</td>
<td></td>
</tr>
<tr>
<td>No fire before or during breeding</td>
<td>20</td>
<td>4</td>
<td>6</td>
<td>24</td>
<td>16.7</td>
<td></td>
</tr>
<tr>
<td>Fire before breeding</td>
<td>71</td>
<td>22</td>
<td>32</td>
<td>93</td>
<td>23.7</td>
<td></td>
</tr>
<tr>
<td>Fire during breeding</td>
<td>13</td>
<td>2</td>
<td>4</td>
<td>15</td>
<td>13.3</td>
<td></td>
</tr>
</tbody>
</table>

Although these results give the suggestion that fire prior to the breeding period gives a greater chance of success, analysis showed that this was not significant (Chi-square=1.19, df=2, p=0.55). The number of fledglings produced in each fire incidence category was also of interest as it may be that Babblers are timing their breeding.
periods with respect to fire so as to gain the maximum resource potential of an area and, thus, successfully fledge more young. As the data are not normally distributed, the Kruskal-Wallis test was used for this analysis; the results were not found to be significant (H=0.91, df=2, p=0.634).

5.3.2.2 Fire and group size
For the GLMM analysis, the null hypothesis was that the proportion of territory burned in the previous year (‘Fire’) has no effect on the size of Babbler groups in the following year. A summary of the results from the GLMM analysis in R is presented in Table 5.5.

In all scenarios the z-values are within the range specified, therefore the null hypothesis is not rejected.
Table 5.5 Summary of R output of the results of GLMM examining relationships between groups size in subsequent year and the proportion of “territory” burnt, using estimated territory sizes of 10, 20 and 50ha and relative proportions of territory burnt; EMD=Early-mid dry season, LD=Late dry season.

| Territory size (ha) | Time of fire | Fixed effect | Estimate | STD error | Z value | Pr(>|z|) |
|--------------------|--------------|--------------|----------|-----------|---------|---------|
| 10                 | EMD          | (Intercept)  | 1.3420   | 0.1387    | 9.676   | <2e-16  |
|                    |              | Fire         | 0.2451   | 0.2413    | 1.016   | 0.31    |
|                    | LD           | (Intercept)  | 1.4519   | 0.1239    | 11.717  | <2e-16  |
|                    |              | Fire         | -0.0301  | 0.3202    | -0.094  | 0.925   |
|                    | Overall      | (Intercept)  | 1.3168   | 0.1822    | 7.227   | 4.92e-13|
|                    |              | Fire         | 0.1889   | 0.2262    | 0.835   | 0.403   |
| 20                 | EMD          | (Intercept)  | 1.3455   | 0.1478    | 9.103   | <2e-16  |
|                    |              | Fire         | 0.2403   | 0.2734    | 0.879   | 0.379   |
|                    | LD           | (Intercept)  | 1.3987   | 0.1320    | 10.594  | <2e-16  |
|                    |              | Fire         | 0.1616   | 0.3281    | 0.493   | 0.622   |
|                    | Overall      | (Intercept)  | 1.2748   | 0.1861    | 6.850   | 7.37e-12|
|                    |              | Fire         | 0.2460   | 0.2283    | 1.077   | 0.281   |
| 50                 | EMD          | (Intercept)  | 1.3520   | 0.1571    | 8.605   | <2e-16  |
|                    |              | Fire         | 0.2442   | 0.3294    | 0.741   | 0.458   |
|                    | LD           | (Intercept)  | 1.3984   | 0.1558    | 8.977   | <2e-16  |
|                    |              | Fire         | 0.1454   | 0.3921    | 0.371   | 0.711   |
|                    | Overall      | (Intercept)  | 1.3216   | 0.1902    | 6.949   | 3.68e-12|
|                    |              | Fire         | 0.1776   | 0.2359    | 0.753   | 0.451   |
5.4 Discussion

5.4.1 Patterns of fire across the study site
Fifty to seventy percent of the savanna landscape in the top end of the Northern Territory is burnt annually (Williams and Cook 2001a) and the Coomalie region is no exception with an average of 60% burnt per year (Price and Baker 2003).

Fire patterns across the study site varied little over the 5-year study period, other than that the late dry season data for 2007 showed an increase in MPS for the recent fire category and an increase in the percentage of the total area burnt for the late dry season in that year.

Patterns of fire in the tropical savannas are greatly influenced by the timing and intensity of rainfall (Russell-Smith and Yates 2007). The Bureau of Meteorology noted that the Northern Territory wet season for 2006/2007 did not see the monsoon set in across the top end region until about three weeks later than average, around the middle of January (Bureau of Meteorology 2007). Although the rainfall recorded for the season was in keeping with average total rainfall for the season, this delay could have had a ‘knock-on’ effect on the dry season fires. Fuel loads may have taken longer to accumulate thus resulting in a smaller proportion of the site being burnt in the early-mid dry season and then a larger amount ultimately burning in the late dry season as evidenced in Table 5.1

A constraint for this study in interpreting the impact of fire pattern is the limited number of fire images available; ideally, to observe fire patterns at this scale, weekly or monthly images would be far more revealing of trends. It is also challenging to put these data in context with other fire experiments in the northern savannas as the majority of other studies involve experimental fire regimes controlled by the researcher unlike at Coomalie Farm where the fires were completely independent of research being undertaken.

5.4.2 The effect of fire on breeding success
Although there can be little doubt that fire exerts a strong influence on the ecology of birds in the tropical savannas, a direct link between fire and the breeding success of Grey-crowned Babblers could not be determined in this study.
5.4.2.1 Timing of fire

Studies by Woinarski *et al.* (2004) and Legge *et al.* (2008) undertaken in Litchfield National Park in the Northern Territory and the central Kimberley in Western Australia respectively, both found Babbler population numbers increased in burnt sites. However, in the study in Litchfield, approximately 20km from Coomalie Farm, it was noted that although there was an increase in the Babbler population in areas that experience frequent fire, this did not occur if the site had been burned during the late dry season. The results of the current study found that the greatest percentage of successful nests was found in areas that experienced both early-mid and late dry season fires. This may be the Babblers preferred fire regime as the early fires would clear away fuel loads, not only aiding in foraging but reducing the intensity and possibly the frequency of later fires due to minimal fuel build-up. Later fires would then be less damaging to vegetation but would again provide greater accessibility to food sources by clearing away understorey growth. In contrast, nest sites that experienced late dry season burning only returned the lowest percentage of successful nests concurring with the results of Woinarski *et al.* (2004). Nonetheless, these observed responses were relatively minor, and the analysis demonstrated no significant difference in nest success across the different fire regimes encountered in this study. However, the interpretation of these results may be constrained or affected by some methodological issues:

1. The retrospective nature of the study and the use of data gathered by another research team
2. No experimental fire regimes were created. All fires that occurred were regular annual prescribed burning or wildfires;
3. Because data had been collected several years prior to my beginning the study, there is no clear delineation of Babbler territories. This means that the proportions of surmised territories burned are highly speculative;
4. Insufficient contrast in fire patterns between years and Babbler territories which meant that analyses concerning fire and breeding success spanned only a relatively narrow and subtle range of fire differences.

Woinarski *et al.* (2004) experienced similar challenges in their Litchfield study and suggested that it may be the extent of fire through an animal’s habitat or territory that has the greatest impact rather than that of the immediate area e.g. nesting sites.
5.4.2.2 Fire and group size

The aim of the investigation into the effect of fire on group size was to observe the impact of a short-term fire history on Babbler breeding success. That no significant effect was determined suggests that a mid-to-long term fire history is required to fully examine any potential consequences and that analysis should extend to environmental variables that are directly affected by fire (soil nutrients, vegetation etc).

A study on Splendid Fairy-wrens in Western Australia Russell and Rowley (1993) found a decrease in group sizes and breeding success three years after a major fire through the habitat; this was attributed to the lower numbers of fledglings being produced during the years following the fire and the inexperience of new breeding females. It is difficult to draw a parallel between this and the current Babbler study as although Russell and Rowley (1993) state that fire is frequent though the study area, it is nothing like the fire regimes experienced in the tropical savannas (the WA study site was recorded as being affected by eight fires since the year 1973 whereas approximately 60% of the Coomalie region burns each year (Price and Baker 2003; Prudent-Richard et al. 2010)) Woinarski et al. (1999) and Woinarski et al. (2004) both found that a 6-year fire history in the Victoria River District and Litchfield National Park was too short to determine any clear changes in vertebrate responses although both did record a short-term response to fire by insectivorous birds which moved to forage in recently burnt areas.

Many fire history studies, both Australian and international, focus primarily on changes in abundance of birds within an area with relation to the fire history (Pyke et al. 1995; Madden et al. 2000; Smucker et al. 2005; Legge et al. 2008) but few have investigated the specific effect upon reproductive ecology. One such study by James et al. (1997), however, determined that fire history indirectly affected the clutch sizes of Red-cockaded woodpecker (Picoides borealis) by directly impacting upon soil nutrients and, thus, health of the birds in the area.

This study is one of the very few to investigate the effect of an established fire regime on Grey-crowned Babblers. Previous studies have looked predominantly at the effect of prescribed, fuel reduction burning in remnant habitats (Davidson and Robinson 1992; Adam and Robinson 1996). Therefore, regardless of the limitations, the results from the current study raise some interesting questions: If fire isn’t directly contributing to the low breeding success rate in the Coomalie Babbler groups, is it interacting with other
factors? If so, how might this combined effect contribute to nesting failure?

There is evidence to suggest that fire and nest predation can have a compound effect on avian breeding success (Benshemesh 1990; Recher 1991; Brooker and Brooker 1994). It is reasonable to assume that predation is a major, if not the major, cause of nest failure recorded in this study. Eguchi et al. (2007) noted that predation made up 60% of the nest failures of the Coomalie Babblers documented between 2003 and 2005 and it is widely accepted that the levels of nest predation can be extremely high in tropical bird species (Oniki 1979; Skutch 1985; Stutchbury and Morton 2001).

As insectivores, Babblers forage in leaf litter and under bark on plant limbs and trunks (Higgins and Peter 2002; personal obs). The clearing away of understorey grass and shrubs by fire may aid foragers in finding prey. It could also be speculated that vegetative regrowth, particularly that of savanna grasses, after fire may attract new suites of insects to Babbler territories thus making the choice of nesting site one based on food availability rather than protection from predators.

5.5 Summary

In summary, fire could not be directly connected to Babbler breeding success in this study. Analysis of the fire maps available showed minimal changes in fire patterns across the study site for the five years of the study.

A vast majority, over 80%, of breeding sites were burned at least once during the time span of the study; however, the history of the site (burned or unburned) was found to have had no significant effect on nesting outcome. Although the highest proportion of successful nests were those in areas that were determined to have experienced both early-mid and late dry season fires in a year, analysis did not find the timing of fire to be statistically significant in influencing the nesting results. Assessment of nest success and number of fledglings produced with respect to the incidence of fire relative to breeding again found no statistical significant effect.

Analysis by Generalised Linear Mixed Modelling (GLMM) on the impact of short-term fire history on group size and, thus, breeding success again showed no statistically significant effect.
Chapter 6
Discussion of the Findings of the Study Including Limitations, Management Implications and Future Research
Chapter outline
This chapter provides an overall summary of the results obtained in this project. A critical discussion on the use of spatial data is also included and limitations of the study are acknowledged. The thesis concludes with the result of this study being placed in a managerial context and suggestions for future research put forward.

6.1 Preamble
Some notable work has already been done regarding the responses of cooperatively breeding species and fire. James et al (1997) conducting research on the effects of a prescribed fire regime fire history on the Red-cockaded Woodpecker in northern Florida, USA, suggested a link between the impact of fire on soil nutrient dynamics and animal health. A further study on another Florida species, the Florida Scrub-jay, by Schoech (1998), in which prescribed burning of the habitat is implied but not explicitly stated, found that the suppression of fire was having a detrimental effect on the birds by favouring a secondary species which then excluded the Florida Scrub-jay from the habitat.

Within Australia, most of the studies conducted are in relation to the effect of intermittent fires, such as Russell and Rowley (1993) with their research into the Splendid Fairy-wren, Malurus splendens. This study, conducted over more than 15 years, recorded eight fires in the study area between the years 1973 and 1988 and concluded that, along with brood parasites, fire was the major cause of demographic variation. A delayed decline in fledgling production was seen three years after a major fire in 1985 and the number of non-breeding birds increased due to the absence of suitable territories. Alternatively, Ward and Paton (2004) discovered that Slender-billed Thornbills in Ngarkat Conservation Park, South Australia, peaked in abundance in burnt heath areas seven years after a major fire whereas those that inhabited unburnt, mature heath were in lower, less variable densities. Intriguingly, group sizes did not vary between burnt and unburnt heath. It was concluded that frequent fires were not necessary for population persistence of this species.

Similar to Russell and Rowley (1993), Nakamura et al (2010) recorded larger non-
breeding flocks of *Malurus melanocephalus cruentatus*, the Red-backed Fairy-wren, in burnt sites in tropical savanna woodland than in unburnt sites. Here, too, fires affected group organisation and resulted in territories needing be re-established.

The Grey-crowned Babbler has been extensively studied in southern Australia (King 1974; Edwards and Kot 1995; Blackmore and Heinsohn 2007). Their habitat preference is open woodland, which can facilitate the study of several groups simultaneously and they are considered easier to watch than many other species (Brown and Brown 1981). They are also very social and have a distinctive vocal range (Higgins and Peter 2002) making locating groups relatively simple.

Whilst the southern subspecies, *P. temporalis temporalis*, has been investigated to some extent with respect to fire (Adam and Robinson 1996) there has been no previous consideration for its northern counterpart. This study provides some of the first information gathered about how Grey-crowned Babblers in the tropical savannas may be responding not only to single fire events but also to short-term fire histories within a 5-year period in a relatively undisturbed habitat.
6.2 Summary of results

The breeding results of the Coomalie Babbler groups recorded for five years between 2003 and 2007 showed that success rates were low. Indeed, the results from this study are comparable to some studies in southern Australia where Babbler habitats have been significantly modified and populations are under threat. Whilst there appear to be no indications that Babbler numbers are in any danger of declining significantly in the Northern Territory a detailed study of populations is yet to be done.

Unlike Babblers in southern Australia, and at odds with traditional paradigms of tropical bird species, the average number of nesting attempts made by the Coomalie groups was under two per year, noticeably less than recorded in some studies undertaken in temperate Australia. As, on average, over fifty percent of nesting commenced in the September/October period, it may be speculated that there is a short window of easy food availability for the Babblers in this area thus restricting the number of breeding attempts. The early-mid dry season fires (May-July) clear away understorey vegetation making ground foraging easier and subsequent regrowth attracts insects to the area. It would, therefore, be advantageous to time breeding periods for the late dry season (August-October) when food levels are at their peak. However, soon after the wet season begins (December-January) with the arrival of monsoon troughs, a rapid increase in vegetative growth makes ground foraging increasingly difficult.

In agreement with other studies on this species, increased breeding success was found to be correlated with increasing group size. However, the number of fledglings per bird in successful nesting attempts was inversely related to increasing group size suggesting that this may be linked to the individual fitness of group members (Dickinson and Hatchwell 2004). Other studies on Grey-crowned Babblers found that larger groups produced more fledglings (Brown and Brown 1981; Blackmore and Heinsohn 2007); the groups at Coomalie Farm may be limited in that the habitat can only optimally support groups of certain size (Balda and Brown 1977; Brown 1987).

A direct link between fire and breeding success could not be statistically established in this project although there were tantalising suggestions that fire and fire regimes could be playing an important part in the Babblers breeding ecology. Analysis of breeding results relative to the incidence of fire hinted that fire prior to the breeding period gave a greater chance of success however it was not found to be statistically significant. The
greatest number of fledglings produced also occurred from nesting sites that experienced fire prior to the breeding period giving credence to the view that the birds may be timing breeding to coincide with optimum foraging opportunities (e.g. when early fires have cleared away dense understory and regrowth attracts insects to the area). Once again, however, analysis did not show a statistically significant effect.

An indirect link of fire and breeding success was explored by analysing the short-term fire history of nesting sites and its potential effect on group sizes. Studies on cooperatively breeding birds in Africa and America have found both direct and indirect effects of fire on group size (James et al. 1997; Pons and Wendenburg 2005); however, I found it difficult to find any data from Australia, let alone the tropical north. The use of EYN gave both a more complete history (four years from five) and, as these groups showed very little movement between nesting sites across the five years, I could be reasonably certain that the groups were affected by the fire history in that area. It can be reasoned that as group size had been shown to have an effect on breeding success in chapter 5, an effect of fire on group size could then ultimately affect breeding success. The subsequent GLMM analysis did not find an effect of fire on group size.

6.2.1 Addressing the primary aims of the project

In summary, addressing the primary aims:

1. **To determine the breeding success of Babblers at a specific study site in the northern savannas and whether it is significantly different to that seen in studies in southern Australia.**

   The breeding success of Babblers at Coomalie Farm was low but within the range found throughout Australia. Nesting attempts were less than in other Australian studies; however, as with southern studies, it was not uncommon to find successful nests often fledged more than one youngster.

2. **To investigate the relationship between group size and breeding success and group size and number of fledglings produced.**

   As with prior studies of both this species and other cooperatively breeding birds, a positive association was found between increasing group size and breeding success. The relationship between group size and fledglings numbers was less clear, however, with a general trend towards increasing fledgling numbers with increasing
group size but when analysis was performed on number of fledglings per bird in successful groups, a negative correlation was seen. It is speculated that this is due to a relationship between habitat quality and individual fitness of group members. In poor conditions it may be that group size is seen to have a greater effect on reproductive success, however the fitness of individual members may be less than in good conditions when the effect of group size is less pronounced. Further study is necessary to clarify this.

3. **To explore whether there was a difference in breeding success between burnt and unburnt nest sites.**
   
   With years both separated and combined, no statistically significant link was found between the fire status of the site (burnt or unburnt) and the outcome of breeding attempts (success or failure). This may, in part be due to the fact that it was unlikely for any nest to be in an area that didn’t experience fire during the breeding season (22% of successful nests).

4. **To investigate the effect of the fire history of a nesting site on breeding outcomes.**
   
   Using group size as a random variable in that it was known that group size and breeding success were correlated, an analysis of the short-term fire history of a nesting site found no statistically significant effect of fire upon breeding success. However, it is suggested that more than five-years worth of data are needed to determine any effect on breeding and that other variables, such as soil nutrients, need to be included in an analysis of this kind as fire may have an indirect effect on the breeding outcomes.

5. **To examine breeding results with respect to the timing of fire within a given year.**

   Whilst no statistically significant relationship between the timing of fire and nesting success or the number of fledglings produced, the highest proportion of successful nests were found in areas that experienced both early-mid and late dry season fires. It is thought that it may be the extent of fire through the breeding site rather than the specific timing that may be of most concern to reproductive ecology of the Babblers. Research that measures the proportion of breeding territory area burnt with each fire event, its impact on vegetation and food resources would greatly aid in determining the effect of fire on Babbler reproductive success.

Based on the results found in this study, fire has no direct statistical effect on breeding
success; however it is more likely that there is an indirect effect. The fire regime rather than individual fires could be impacting on the Babblers reproductive ecology and, therefore, the timing of the annual fires may have the most significant effect. The fact that the number of groups recorded as breeding each year seems to be in decline is something of a concern but without ongoing research it is hard to know whether this is due to the inexperience of novice breeding pairs, a year when breeding is simply not viable due to habitat quality, higher predation rates or something as yet undetermined. The Coomalie subregion is recognised as a home to important ecosystems and species vulnerable to habitat and climate change (Prudent-Richard et al 2010). It is therefore vital that ecosystem processes such as fire regimes are better understood. Only by fully understanding how the current fire regime is interacting with other variables can strategies be put in place to protect and maintain the Babblers populations of the region.

6.3 The role of spatial and temporal analysis

Advances in technology regarding remote sensing and geographic information systems have greatly benefited environmental researchers, particularly in regard to retrospective studies such as this one. Indeed, without the availability of satellite imagery across the Coomalie region, this study could not have been undertaken. The application of these techniques in this study allowed an approach to this project from a landscape ecology perspective. The patterns of fire over time and space and how this ultimately might be affecting the Babblers was able to be investigated.

6.3.1 Advantages

There were several advantages to using spatial data and analysis in this project.

This project started in 2007 however the Babbler data used were gathered from 2003 onwards. The research team that recorded the Babbler data were focussing on another aspect of their breeding ecology and, therefore, did not note fire events. Without the satellite imagery acquired through the Landsat-5 satellite system, it would have been almost impossible to comment on past fires across the region. Although the time to complete an orbit is greater than some other satellite systems, the resolution of imagery from the Landsat-5 satellite ranges from 25m² to 33m² which is eminently suitable for small, regional projects such as this. Proportions of areas burnt could be
determined with relative certainty.

The development of a GIS for this project was integral in investigating patterns between the Babblers’ nesting ecology and fire. The interactions between nesting locations and fire maps allowed me to see if Babblers were nesting in areas that experienced fires on an annual basis and whether they continued to do so over a period of time, something that would have again been impossible without the satellite imagery from previous years.

The shapefiles obtained of the Coomalie region had a vegetative component that assisted with habitat delineation of Babbler nesting areas and reduced the amount of time spent in the field. Within the GIS this also allowed for an interaction between habitat types, fire maps and nesting locations to investigate whether Babbler groups were moving habitat zones with respect to fire.

6.3.2 Limitations and disadvantages

Ultimately a GIS is only as good as the data that are entered into it and, to this end, one must be mindful of errors that can occur and undermine their applications to projects. Burrough (1986) divided sources of errors in GIS into three classes:

1. Obvious sources of errors.

   These include:
   - Age of data used;
   - Relevance of data;
   - Scale;
   - Consistency of coverage, particularly if it has come from something like a paper map;
   - Format of data (how it was originally stored e.g. disks, tapes etc and how the measurements are represented and formed e.g. scale, classification and projection).

   The costs and accessibility of data are sometimes included as an ‘obvious source of error’ on the reasoning that if a researcher cannot afford or access the highest quality data, the resulting GIS will reflect this.

2. Errors arising from measurement methods or natural variation.

   Natural variations are those changes that may arise due to ecological processes such
as floods, fires, volcanic eruptions and even vegetative growth. By the time data are input into a GIS a ‘natural’ event, such as a landslide, may have occurred which then leads to the data being outdated and changing analytical outputs.

Measurement errors can be of several types:

- **Positional:** errors in the position of attributes or measurements of map features;
- **Content:** over or under estimating species numbers and misidentification of species;
- **Classification and generalisation:** attributes may be subject to interpolation mistakes which then causes irregularities in data;
- **Bias:** features may be omitted or added due to fault or by design of the analyst.

3. **Processing errors.**

As suggested these are errors that occur during the processing of data and its implementation into a GIS. They can be extremely subtle and, therefore, difficult to detect. Processing errors include:

- **Numerical errors:** these may occur during the digitisation of conventional maps to digital forms;
- **Topological errors:** this can arise during the overlaying processes and can often be cumulative. For example, in an analysis relating vegetation type to soil structure, the soil map utilised may have an accuracy of 70% whereas the vegetation map may have an accuracy of 60%. Therefore, the overall accuracy of the resulting combined map could be as low as 42%.
- **Digitising and geocoding errors:** errors that occur during other data manipulation such as converting street addresses into geographic coordinates.
- **Classification and generalisation:** as above, misinterpretation and erroneous identification of classes or attributes.

As with any project it is important to try to minimise the potential for error in data used or, at least, acknowledge when data may contain errors.

The majority of the processing and assessment of the spatial data used in this project had been done prior to its usage so protocols applied by the relevant government
bodies with respect to their accuracy and precision had to be somewhat relied upon. Cross checking was done with the use of aerial photography and fieldwork (coordinates of landmarks and vegetation surveys).

The greatest potential for error in the GIS was in the classification of fire maps prior to 2006. For years 2006 and 2007 fieldwork and ground control points could be used to determine the accuracy of images (see chapter 3), however, this could not be applied to the images taken for 2003, 2004 and 2005. To this end, some reliance was made upon the classification method utilised by ERDAS Imagine and interpretations of the resultant fire classes with respect to those fire images that could be accuracy assessed by ground control points. Similar methods have been used in previous projects using retrospective fire imagery (Edwards et al. 2000; Price and Baker 2003) and these techniques are becoming accepted practice for studies such as this.

6.4 Limitations of this study

There were several limitations on this study.

Foremost, breeding data generously supplied by another research team had to be relied upon. Whilst in no way being less grateful for the kind assistance given on this project by Associate Professor Kazuhiro Eguchi and Professor Keisuke Ueda and their research team, the simple fact remains that the Babbler breeding data were originally gathered for another research purpose. Therefore details of nest sites (for example, vegetation composition and fire effects at time of data gathering) were not available and can only be interpreted from a present day viewpoint. Although individual birds were banded, without modern tracking devices, group territories could not be accurately determined leaving the use of minimum and maximum territory sizes as defined by studies in southern Australia.

Due to the project being retrospective in its nature, details of fire at the sites for years 2003-2005 could only be obtained via the satellite imagery. This in itself was limited by the fact that only two images per year were available to cover the primary Babbler breeding season recorded. There is the likelihood that fires were far more frequent than suggested by the images. Although the Landsat-5 TM imagery used is of high resolution and was able to be accessed free of charge, there are now images of higher
resolution being gathered by alternative satellite units that were not as available or as financially viable when this project started. As noted previously, GIS and spatial methods are benefited by using the highest quality available data and techniques. Time constraints limited the fieldwork undertaken to vegetation surveys and observing, when possible, Babbler foraging behaviour. Although useful for gathering a certain amount of ground control points for use in the accuracy assessment of some of the satellite images, foraging data gathered were not enough to carry out any significant statistical analysis.

If not limited by time and money, this project would have benefited from a detailed, current vegetation survey of the study site. Foraging behaviour and investigations into the response of Babbler prey insects to fire could have been undertaken to see if this was the link to the effect of fires on reproductive success. Groups could have been radio or satellite tracked to delineate territories and observe rival group interactions. The commission of more regular satellite images and the ability to more regularly visit the site for ground-truthing would also have been of benefit in giving a more detailed, overall picture of the fire regime.

To this end it is difficult to state with any certainty what the results determined in this project might mean for the future of the Babblers at Coomalie Farm. The provocative hints that fire and fire regimes may be influencing the breeding ecology of Grey-crowned Babblers deserve further, more thorough investigation preferably based on experimental manipulation of fire regimes that could more crisply demarcate fire contrasts and resolve the Babblers’ responses to fire.

6.5 Management implications and future research

6.5.1 Management

Whilst their populations seem secure in the savannas of the Top End, like most species the maintenance of habitat integrity is the foremost issue in the conservation of Grey-crowned Babblers. Outside of land clearing for development, of greatest concern is the increase in frequency of fires in the tropical savannas and the homogenisation of
habitats. The changing of fuel loads by introduced vegetation and, thus, greater fire intensities is also an area that needs to be monitored and managed.

To help manage and maintain the Babbler populations a regular census of groups should be implemented to observe changes over time and what may be facilitating this. Determining the optimum fire regime is of primary importance. As noted in chapter 5, the greatest number of successful nests was found in areas that experienced fires during both the early-mid and late dry season. Woinarski et al (1999 and 2004) noted that Babblers moved in rapidly to forage in recently burnt areas in the tropical savannas; thus, it would be advantageous to implement a fire management programme that maintains this form of burning. An eradication programme for introduced plant species should be considered, particularly with the continuing spread of Gamba grass to limit the effect on fuel loads and fire intensities.

It is difficult to compare management strategies for Grey-crowned Babblers between the southern and northern parts of the country. The Babblers in the south primarily have to contend with severe habitat fragmentation (Davidson and Robinson 1992; Adam and Robinson 1996) and it has been shown in Victoria that fuel-reduction burning is also detrimental (Adam and Robinson 1996). However, the Babblers in the Top End savannas live with frequent fire and may prefer frequently burnt habitats (Woinarski 1990; Woinarski et al 2004; Legge et al 2008). The challenge for the Babblers in the Top End is that with continuing development of northern Australia for both agriculture and residential purposes, habitat quality may be put under threat.

**6.5.2 Future research**

To better understand how fire is affecting this species, research needs to be concentrated on defining Babbler group territories, ideally by radio or satellite tracking of individuals, and the fire regimes therein. Imagery of the region taken at more regular intervals using a higher resolution satellite monitor such as IKONOS (resolution ranges from 1-4m) or QuickBird (61cm-2.4m) would greatly enhance data and enable researchers to better observe the fire patterns of Babbler territories and how these might vary through time. Once a better understanding of current fire regimes is achieved, this may then be used to formulate fire threat models, particularly with regard to climate change scenarios.

A more detailed exploration of group composition and the effect of helpers of each
gender would be of much benefit when analysing breeding results. A study undertaken in New South Wales (Blackmore and Heinsohn 2007) discovered that male helpers increased the likelihood of breeding success and had a profound positive effect on the number of fledglings produced in a season whereas female helpers did not. It would be of interest and benefit to determine whether Babbler groups in the tropical north followed the same pattern.

Detailed vegetation and prey species surveys would greatly aid in determining the role fire plays in affecting Babbler breeding ecology.

The Northern Territory is in a unique position where development can be tempered by lessons learned in other parts of Australia. The Grey-crowned Babbler may seem to be a very small, indeed insignificant, component, in the larger scheme to develop the perceived vast emptiness of the north of the continent. It is not a pretty, brightly coloured bird like the Gouldian Finch, nor is it an imposing bird of prey like the Wedgetailed Eagle. However, that does not make its value to an ecosystem any less essential.
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Appendix

Nest results data

Appendix Table 1 Nest results for 2003; note: for group G2 it was unknown which of two nests recorded the successful result.

<table>
<thead>
<tr>
<th>Group name</th>
<th>Nest name</th>
<th>Group size</th>
<th>Lat.</th>
<th>Long.</th>
<th>Order of nesting attempt</th>
<th>Fail/Success</th>
<th>Number of fledglings</th>
<th>Failure type</th>
<th>Burnt prior to nesting Y/N</th>
<th>Burnt during nesting Y/N</th>
<th>Burnt previous year Y/N</th>
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Failure categories based on 17 days incubation period and 21 days nesting period as per Eguchi et al 2007.
Failure type key: 
- FB = Failed at building stage
- FE = Failed at egg stage
- FN = Failed at nestling stage

Habitat type key: 
- W = Woodland
- G = Grassland
- OF = Open Forest
- FP = Floodplain
### Appendix Table 2 Nest results 2004

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Failure categories based on 17 days incubation period and 21 days nesting period as per Eguchi et al 2007.

Failure type key:  
FB = Failed at building stage  
FE = Failed at egg stage  
FN = Failed at nestling stage

Habitat type key:  
W = Woodland  
G = Grassland  
OF = Open Forest  
FP = Floodplain
Appendix Table 3 Nest results 2005; note: for group G13 it was unknown which of six nests recorded the successful result.

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Failure categories based on 17 days incubation period and 21 days nesting period as per Eguchi et al 2007.

**Failure type key:**
- FB = Failed at building stage
- FE = Failed at egg stage
- FN = Failed at nestling stage

**Habitat type key:**
- W = Woodland
- G = Grassland
- OF = Open Forest
- FP = Floodplain
Appendix Table 4 Nest results 2006; note: for group H44 it was unknown which of two nests recorded the successful result.

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Failure categories based on 17 days incubation period and 21 days nesting period as per Eguchi et al 2007.

**Failure type key:**
- FB = Failed at building stage
- FE = Failed at egg stage
- FN = Failed at nestling stage

**Habitat type key:**
- W = Woodland
- FP = Floodplain
- G = Grassland
- OF = Open Forest
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