Behaviour patterns and habitat use of the Brolga (*Grus rubicundus*) at two flocking sites in south-west Victoria

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Statement of Responsibility

This thesis is submitted in accordance with the regulations of Deakin University in partial fulfillment of the requirements of the degree of Bachelor of Environmental Science (Honours). I, Kristie Anne King, hereby certify that the information presented in this thesis is the result of my own research, except where otherwise acknowledged or referenced, and that none of the material has been presented for any degree at another university or institution:

This project involved the use of animal or human subjects and the project was conducted in accordance with the regulations of Deakin University Animal Ethics Committee under Permit No. A 19/2008:
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Abstract

The Brolga (*Grus rubicundus*) is Australia’s only endemic crane species. Brolga numbers in southern Australia have declined significantly over the last century due to widespread loss of wetland habitats for agriculture. Flocking sites support Brolgas for up to eight months of the year and are therefore an important component of Brolga ecology and conservation. This study sought to obtain baseline information on the spatial requirements of Brolgas at the intra- and inter-site scales. Behavioural and patch use observations were used to assess time budgets, activity patterns, foraging behaviour and foraging ranges of Brolgas at two sites in south-west Victoria.

Habitat use and flocking site selection in Brolgas was found to be dynamic both spatially and temporally. Furthermore, it was found that flocking Brolgas require access to a complex of habitat features distributed in such a way as to minimise energetic travel costs. Important habitat features at flocking sites were determined to include: permanent, protected wetlands for roosting (nocturnally and diurnally); fresh drinking water; crop lands and/or intact waterplant assemblages; and animal food items which provide essential protein and calcium.

Management of Brolga flocking habitat in south-west Victoria should focus on improving the availability and quality of essential habitat features, particularly wetland roosting, drinking, foraging and loafing sites which seem to be limited in availability. As Brolgas appear to be exhibiting preferential flocking site selection, potential risks associated with between-site migrations should be determined and addressed. Future research should focus on detailing the role of temporal and spatial heterogeneity in Brolga habitat use via comprehensive habitat sampling and the application of genetic and stable isotope analysis and telemetry techniques.
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Introduction

Global biodiversity is declining at an ever-increasing rate, predominantly due to the clearance, modification and fragmentation of habitats (Ehrlich and Wilson 1991; Naeem et al. 1994). Waterbirds, which rely on intact wetland habitats for roosting, breeding and feeding, are particularly threatened by the loss of habitat associated with agricultural expansion (Corrick and Norman 1980). Australia’s only endemic crane species, the Brolga (*Grus rubicundus*), is a wetland-dependent species which has suffered severe range contractions in southern Australia over the last century, primarily due to the drainage and modification of the shallow ephemeral wetlands favoured by Brolgas for breeding (Arnol et al. 1984; White 1987; Meine and Archibald 1996). During the non-breeding season, Brolgas congregate at ‘flocking sites’ (known as ‘wintering sites’ in the Northern Hemisphere) where they roost communally on permanent open wetlands and feed in adjacent grasslands and/or agricultural fields (Johnsgard 1983; Arnol et al. 1984; White 1987). The management and conservation of threatened populations requires understanding of the limiting factors which may be operating throughout a species’ entire annual cycle. Despite the fact that Brolgas spend up to 8 months of the year at flocking sites, patterns of behaviour and habitat use during the flocking season are still poorly understood. This thesis reports on a study carried out in south-west Victoria that aimed to contribute to a better understanding of Brolgas and their flocking habitats.
The Brolga (*Grus rubicundus*)

The Brolga is distinguishable by its long neck and legs and the light grey plumage and red head colouration of adult birds (Figure 1.1). Adults stand up to 1.6 m tall and weights range between 3.7 – 7.8 kg (Johnsgard 1983; Marchant and Higgins 1993). Apart from general size differences, sexual dimorphism is low (Johnsgard 1983; Marchant and Higgins 1993). Brolgas are highly omnivorous and will consume a variety of plant and animal items. Natural food items include insects, spiders, molluses, amphibians, small mammals and all parts of wetland plants. The tubers of wetland plants are considered to be a preferred food item, particularly those of the Bulkuru sedge (*Eleocharis dulcis*) (Johnsgard 1983; Marchant and Higgins 1993; Meine and Archibald 1996).

![Figure 1.1. An adult Brolga (*Grus rubicundus*) with eggs.](image)
Distribution

Brolgas are distributed across northern and eastern Australia, with a small population in southern Papua New Guinea (Figure 1.2). Vagrant birds are occasionally sighted in New Zealand. Total population estimates range from 20,000 to 100,000. Major strongholds occur in north-eastern Queensland, where flocks of up to 12,000 birds occur (Arnol et al. 1984; Marchant and Higgins 1993; Meine and Archibald 1996). Once common in New South Wales, widespread habitat clearance has caused range contractions within the state and isolated populations in northern and southern Australia. These populations are now considered to be discrete and reproductively isolated (Arnol et al. 1984; White 1987). The Brolga was formerly distributed widely within southern Australia, with birds reported from coastal east Gippsland to southern parts of South Australia. The current distribution of the southern population is now thought to be largely restricted to the south-west Victorian volcanic plains, with small flocks occurring west of the Hume Highway in the northern plains Riverina area (Arnol et al. 1984; White 1987; Herring 2001) (Figure 1.2). There are also scattered occurrences in eastern South Australia, most notably at Bool Lagoon near Narracorte where flocks of up to 200 are recorded (Sheldon 2004).
Figure 1.2. Distribution of the Brolga (Meine and Archibald 1996).

**Brolga**

*Grus rubicundus*
**Conservation and management**

The majority of Victoria’s land area has been cleared and converted to private agricultural operations. Consequently, a large proportion of Victoria’s wetlands have been drained and modified to make way for grazing and cropping land (Norman and Corrick 1988). This has impacted severely on Brolga numbers in Victoria, which are estimated to range between 600 – 1000 birds (Arnol et al 1984; Herring 2001; Sheldon 2004). The southern population is now listed as threatened under the *Flora and Fauna Guarantee Act (1988)* and is believed to be in decline due to low rates of reproductive success and an aging adult cohort (‘demographic malfunction’) (Arnol et al 1984). Reproductive (‘recruitment’) rates in southern Australia are thought to average around 4.5% immatures (first and second year birds), however due to the lack of long-term monitoring, the accuracy of this estimate is unclear and it is not known whether rates are sufficient to maintain reproductive viability of the population (Arnol et al 1984; White 1987; Herring 2001). The Department of Sustainability and Environment (DSE) has recently instigated a coordinated program to monitor Brolga numbers and recruitment rates at Victorian flocking sites on public and private land (P. Du Guesclin, pers. comm.).

The southern Brolga population is primarily threatened by the modification, drainage and degradation of wetland breeding habitats (Corrick 1982; Arnol et al 1984; White 1987; Meine and Archibald 1996; Harding 2001; Herring 2001; Myers 2001). Mortality of eggs and chicks associated with fox and raven predation, disturbance at breeding sites, and fence entanglement, are also thought to be major limiting factors (Arnol et al 1984; Herring 2001). Adult mortality, while thought to be low, is mainly due to incidental ingestion of poisoned grain, collisions with...
powerlines and possibly displacement from flocking and breeding sites due to disturbance by duck hunters (Arnol et al 1984; Herring 2001).

**Breeding season**

The Brolga breeding season occurs annually and coincides with the onset of the wetter months, which varies with latitude (Johnsgard 1983; Arnol et al 1984; Marchant and Higgins 1993; Herring 2001). The southern population breeds from July to November. Adult cranes form life-long monogamous pair bonds and maintain traditional breeding territories year after year (Johnsgard 1983; Arnol et al 1984; Herring 2001). Clutches of 1 – 2 eggs are laid in large (up to 1.5 m diameter) nests constructed from mounded vegetative material sourced from the surrounding wetland. Chicks fledge at 90 – 100 days and may remain with parents until reaching maturity at 2 – 3 years. Birds start to seek out mates at 3 – 4 years (Johnsgard 1983; Arnol et al 1984; Marchant and Higgins 1993). Breeding habitat of southern Brolgas has been investigated by White (1987), Harding (2001), Herring (2001) and Myers (2001), who found that reproductive success was related to the availability, quality and protection of the shallow freshwater marshes favoured by breeding Brolgas.

**Flocking season**

During the non-breeding season, unpaired birds and families congregate in large flocks on deep freshwater marshes and permanent open water (Arnol et al 1984; White 1987; Sheldon 2004). The timing of dispersal to flocking sites coincides with the drying of ephemeral breeding wetlands at the onset of the drier months. In southern Australia, the flocking season occurs from December to June (Arnol et al 1984; Sheldon 2004). Dispersal between breeding and flocking
sites is thought to be initiated in response to seasonal climatic and habitat variation, however due to the difficulty of tracking flying birds, flight paths and dispersal mechanisms are not well understood (Johnsgard 1983; Marchant and Higgins 1996). Despite high site fidelity, numbers recorded at flocking sites have declined significantly over the past century. In the early 1940s, around 1450 birds were recorded at a flocking site near Willaura (Sheldon 2004); today, estimates at Willaura and Bool Lagoon (considered to be major flocking sites in southern Australia) rarely exceed 200 (Herring 2001; Sheldon 2004).

**Flocking behaviour**

Whilst being fiercely territorial during the breeding season, Brolgas will roost communally and forage in non-related foraging flocks (social foraging) during the flocking season (Arnol *et al* 1984; Johnsgard 1983; Marchant and Higgins 1993). The function and evolution of communal roosting in birds is thought to be related to enhanced predator detection through collective vigilance (‘many eyes’ effect), reduced predation risk due to the presence of other individuals (‘dilution’ effect), and reduced nocturnal thermoregulatory costs Pulliam 1973; Krebs and Davies 1993; Beauchamp 1998). Social foraging may also reduce predation risk and thereby increase the amount of time available for foraging (Pulliam 1973; Krebs and Davies 1993; Beauchamp 1998; Fernandez-Juricic *et al* 2004; Gardner 2004; Aviles and Bednekoff 2007). The presence of conspecifics (individuals of the same species) may also act as a cue to indicate the location of rich foraging patches, resulting in the formation of large foraging flocks (‘local enhancement’) (Beauchamp 1999; Fernández-Juricic *et al* 2004).
The factors underlying flocking behaviour (i.e. communal roosting and social foraging during the non-breeding season) in Brolgas have not been investigated in detail. Herring (2001) attributed communal roosting to predation avoidance, however as adult mortality due to predation is thought to be low, flocking behaviour is unlikely to be related to predation. White (1987) suggested that flocking behaviour facilitated pair bond formation. In southern Australia, where the major factor limiting many waterbird populations is the availability of surface water, it is likely that flocking behaviour is not a functional adaption but rather the result of aggregation due to a scarcity of suitable roost wetlands and/or foraging sites (Sheldon 2004).

**Flocking season foraging habitats**

Crane populations traditionally obtained most of their food in grasslands and utilised wetlands for roosting, drinking and feeding (Harris 1992; Meine and Archibald 1996). However, in light of widespread degradation of natural habitats, many cranes have learnt to adapt migratory and foraging behaviour to make use of agricultural food resources such fallen corn kernel and wheat grain left after harvest (Johnsgard 1983; Harris 1992; Meine and Archibald 1996). In the Northern Hemisphere, agricultural resources now constitute an essential component of crane diets, and in many places, crane numbers have increased significantly at new flocking sites in response to agricultural expansion (Reinecke and Krapu 1986; Bautista *et al* 1992; Guzman *et al* 1999; Tortosa and Villafuerte 2000; Aviles *et al* 2002; Okes *et al* 2008).

Where natural grassland and wetland food resources are limited, Brolgas can also adapt foraging patterns to make use of food resources from agricultural land; in southern Australia, Brolgas now subsist almost entirely on such resources (Arnol *et al* 1984; White 1987). Flocking season diets
are thought to consist mainly of residual cereal grain left in crop fields after harvesting (‘stubble’ fields); in south-west Victoria, Brolgas are often observed feeding in wheat, barley and triticale (a wheat-rye cross) stubble fields (Arnol et al 1984; White 1987; Pizzey 1994; Sheldon 2004). Birds have also been observed foraging in newly-sown crops, wetlands, and sheep and cattle pastures. Northern Victorian Brolgas have been found to eat the residual grain of corn, wheat, barley and rice (Herring 2001).

**Time budgets and activity patterns**

Animals have a limited amount of time and energy available to devote to foraging, growth, maintenance and reproduction (Pianka 1988; Aviles and Bednekoff 2007). Consequently, assessing how the members of a population allocate time to different activities (e.g. foraging, resting) can provide insights into the species’ habitat requirements and factors which may be limiting the population (Pianka 1988; Alonso and Alonso 1992; Sutherland 1996; Aviles and Bednekoff 2007). Animals make time-allocation decisions based on internal factors such as satiety level, nutritional requirements and endogenous (innate) diurnal rhythms (Caraco 1979; Alonso and Alonso 1985, 1992, 1993; Alonso et al 1995). These factors are in turn influenced by external factors such as seasonal and temporal cues (e.g. light intensity, photoperiod, climatic variation), food availability and resource distribution (Caraco 1979; Alonso and Alonso 1985, 1992, 1993; Alonso et al 1995; Mysterud and Ims 1998). Thus an analysis of time-budget decisions and activity patterns can reflect both a taxon’s innate behavioural adaptations and the environmental factors which may be limiting populations. Researchers have used direct measurements of crane behaviour obtained via observational sampling methods described by Altman (1974) to assess crane time budgets (i.e. proportion of time devoted to different activities
each day) and activity patterns (i.e. distribution of different activities across different times of
day) (Alonso and Alonso 1993; Aviles et al 2002; Aviles 2004; Bradter et al 2007).

The functional unit of foraging behaviour studies is usually the foraging patch (Morrison et al
2006). Hassel (1978) defined a patch as ‘a spatial unit of the predator’s foraging area – one
whose appropriate dimensions are not set by what we perceive, but by the predator’s foraging
behaviour’. In reality, patches are inconsistently defined and researchers usually delineate patch
boundaries as study requirements dictate; for example, Bautista et al (1995) studied Eurasian
Cranes in Spain and defined a patch as ‘one or a few adjacent farms where the flock . . . spent
some time foraging between two flights’. Foraging behaviour in cranes involves travelling
(usually flying) to foraging patches, moving around patches while searching for food (walking
while scanning the ground with head below the shoulders) and actively feeding (standing
stationary with head down below the shoulders). Another crane activity often investigated in
time budget studies is non-essential behaviours such as loafing, stretching, bathing and self
preening (Johnsgard 1983; Masatomi 2004). The prevalence and duration of foraging activities
and comfort behaviours can be used to make inferences about the relative quality of crane
habitat.

Cranes typically exhibit bimodal patterns of diurnal (daily) activity, whereby morning and
afternoon foraging peaks are separated by a midday period of drinking and comfort behaviour at
a wetland (Shields and Benham 1969; Sugden et al 1988; Alonso and Alonso 1992; Bradter et al
2007). Typical crane activity patterns have been found to wane when intake rates are limited by
available foraging time, high energetic costs (due to patchy distribution of habitat features) or
poor food availability (Aviles 2004; Li and Rogers 2004). Walkinshaw (1973) reported that Brolgas in northern Australia foraged ‘intensively’ in the morning and ‘extensively’ in the afternoon, however little is currently known about Brolga time budgets/activity patterns or the nature of their relationship to habitat quality and flocking site selection.

Foraging ranges
The extent of an animal’s range is determined in part by the quality and distribution of habitat features such as foraging, sleeping and drinking sites (Agetsuma and Nakagawa 1998; Mysterud and Ims 1998; Morrison et al 2006). Optimal foraging models predict that animals should select sites which minimise the energetic costs of moving between habitat features while maximising net energy gain from foraging (Norberg 1977; Stephens and Krebs 1986; Krebs and Davies 1993). Foraging ranges have been determined for Sandhill Cranes (8 km from roost; Reinecke and Krapu 1986); White-naped Cranes (3 km; Bradter et al 2007), and Eurasian Cranes (up to 40 km; Bautista et al 1995; Guzman et al 1999). Herring (2001) found that Brolga flocks in the Murray Riverina area foraged within an area of 200 – 1000 ha at distances usually 1 km but up to 5.2 km from nocturnal roosts. Foraging ranges can be used as an indication of the spatial requirements of flocking cranes and are therefore an important component of flocking ecology (Morrison et al 2006), however there is currently no information on foraging ranges of Brolgas at flocking sites in south-west Victoria.

Flocking site selection
Selection of flocking sites can have important implications for body condition and fitness during the flocking season (Herring 2001). It follows then that when food and habitat availability
exceed requirements, cranes will select flocking sites where energetic foraging costs (e.g. due to travel, searching and food handling) are outweighed by energetic returns (e.g. due to high resource availability, low variability, low handling time) (Stephens and Krebs 1986; Alonso and Alonso 1992; Krebs and Davies 1993). For example, Eurasian Cranes arriving at wintering grounds in Spain initially select the flocking sites where foraging patches are closest to the roost to conserve post-migration energy stores, later seeking out more resource-rich patches as energy is recovered (Alonso et al. 1987, 1994; Alonso and Alonso 1992). The breadth of nutritional value available at flocking sites may also impact habitat selection; for example, Sandhill Cranes wintering in North America have been shown to select sites which offer both high-energy corn stubble and pasture fields which provide protein from invertebrates and other animals (Guthery 1975; Iverson et al. 1985; Reinecke and Krapu 1986).

Flocking site selection may also be related to the availability of important habitat features such as roost wetlands. Use of flocking sites is thought to be traditional in Brolgas, whereby immature birds learn the location of traditional flocking sites by migrating with parents (i.e. site fidelity) (Johnsgard 1983; Arnol et al. 1984; Harris 1992; Sheldon 2004). Researchers have identified several habitat features which are common among Brolga flocking sites: i) deep freshwater marshes and/or permanent open water of area >30 ha; ii) adjacent cropping and/or grazing land; iii) buffering from noise and disturbance (Herring 2001; Sheldon 2004). Despite a broad understanding of characteristics commonly observed at flocking site, site selection in Brolgas is not well understood.
Research aims and objectives

Sheldon (2004) characterised and modeled south-west Victorian flocking habitat at the landscape scale and found that suitable flocking habitat, as identified by GIS modeling, was not fully utilised by Brolgas. While substantial areas of potentially suitable flocking habitat were identified, the majority of the southern Brolga population is still accounted for at only four or five major flocking sites (Sheldon 2004). This suggests that Brolgas may be actively selecting some flocking sites over others; if this is the case, the specific qualities that comprise a ‘preferred’ site need to be identified in order to effect appropriate management of Brolga habitat. This study sought to elucidate patterns of Brolga behaviour and habitat use at flocking sites in south-west Victoria at a scale finer than previously investigated (i.e. within-site scale). Four specific research objectives were identified for the study, these being:

1. To estimate bird numbers and recruitment rates at two major flocking sites;
2. To determine Brolga time budgets
3. To determine Brolga activity patterns;
4. To investigate patterns of behaviour and habitat use;
5. To estimate ranges to determine spatial requirements of Brolgas at flocking sites.

The information gained from these research objectives will be used to identify potential limiting factors and important habitat features at flocking sites. Research was carried out during the 2008 flocking season at two major flocking sites in south-west Victoria. It is anticipated that the results of this study will enhance understanding of Brolga flocking ecology and help inform efforts to manage and conserve Brolga flocking habitat in southern Australia.
Methods

Study area

The study area is located within the Glenelg-Hopkins Catchment in south-west Victoria and is roughly bounded by the townships of Penshurst, Dunkeld, Willaura and Lake Bolac. The south-west Victorian climate is temperate with hot, dry summers and cool, wet winters (GHCMA 2003). Evaporation is highest in January and lowest in July (BOM 2008). Annual rainfall varies within the region from 500 mm near Lake Bolac to 900 mm near the Grampians (GHCMA 2003).

The study area is located on the Western District Volcanic Plains, a region of extinct volcanoes with low plateaus and stony outcrops associated with old lava flows (Joyce 1983). The northern portion is characterised by flat to undulating volcanic plains marked with numerous shallow depressions and chains of small lakes. Plains are covered with a thick and continuous layer of yellow-brown duplex soils or red clays (GHCMA 2003; Joyce 1983). The southern portion is characterised by young lava flows of irregular relief and basalt stony rises, which are most extensive around lava volcanoes such as Mount Rouse. Soils are generally thin brown-black clay soils and yellow duplex soils (GHCMA 2003; Joyce 1983).

The majority of land within the study area has been cleared for agriculture and is privately owned. Major agricultural operations are sheep and beef grazing, with some cropping of cereals such as wheat and barley ( GHCMA, 2008). There are few public reserves across the south-west and residential settlements are generally sparse (GHCMA, 2003). The region’s original
grasslands, open woodlands and wetlands have declined dramatically since European settlement and now exist mainly on private land and in small patches on public reserves (GHCMA, 2003). A major portion of south-west Victoria’s wetlands have been drained and modified since European settlement (Arnol et al 1984; White 1987; Sheldon 2004).

**Study sites**

For the purposes of this study, a flocking site was defined as the area surrounding a wetland where Brolgas are known to roost communally during the non-breeding season. Consultation with DSE and preliminary field work revealed two major sites which together were thought to account for a large proportion of the population during the flocking season. These two sites were selected as study sites as they were thought to provide the most representative sample of the south-west Victorian Brolga population. Both study sites were located on private land where landholders had established relationships with DSE for the purposes of Brolga monitoring. Further consultation with landholders enabled access to their land and provided contact details of landholders of adjacent properties where Brolgas were thought to occur. Study sites were labeled according to proximity to townships in order to maintain anonymity of properties at the request of landholders. Wetlands within study sites were classified using the system devised by Corrick and Norman (1980) which is based on salinity, water regime and vegetative assemblage.
Site 1. Penshurst

Site 1 was located north-east of Penshurst on three adjacent farms and covered a land area of approximately 29 km². Major agricultural productions on the properties include sheep and cattle grazing and some cereal cropping. Average rainfall in the Penshurst region is approximately 600 mm/year and average maximum and minimum temperatures are 18.9°C and 7.5°C respectively (GHCMA 2008; BOM 2008). Murdum and Cox Creeks run through the site and each has been impounded at a number of points along shallow drainage channels (Norman and Corrick, 1988) (Figure 2.1). Wetlands within the Penshurst site were deep permanent open freshwater ($n = 6$); four of these had some patches of emergent vegetation (Figure 2.3). All wetlands are subjected to grazing by livestock at some point throughout the year (A. Rentsch, J. Ritchie, pers. comm.).

Figure 2.1. Hydrological map of the Penshurst study site (filled section) and surrounding area.
Site 2. Willaura

Site 2 consisted of two adjacent farms west of the township of Willaura at the southern base of the Grampians National Park and covered an area of approximately 25 km$^2$. Wheat cropping and Merino wool are the major agricultural operations at the site. Average rainfall in the region is approximately 550 mm/year (GHCMA 2008); average maximum and minimum temperatures are 18.8°C and 6.8°C respectively (BOM 2008). Saline groundwater flows dominate inputs into terminal lake systems at this site, giving rise to a series of three major semi-permanent salt pans (Figure 2.2). While small of pockets of littoral vegetation had been replanted around one of these wetlands, all were generally devoid of littoral, emergent and submerged vegetation (Figure 2.4). Two wetlands were surrounded exclusively by crop land and one was surrounded by crop and grazing land on either side of the perimeter.

Figure 2.2. Hydrological map of the Willaura study site (filled section) and surrounding area.
**Figure 2.3.** Permanent open freshwater wetland at Penshurst.

**Figure 2.4.** Semi-permanent salt plan at Willaura surrounded by standing wheat crop.
**Field methods**

Fieldwork was conducted during the 2007-08 flocking season from 11 April – 5 July 2008. Study sites were visited alternately at 2-week intervals from April to May, and then intermittently until July. Field work was carried out at each site for 2 – 3 days at a time. Preliminary field work focused on the identification of roost locations and collection of ethnographic data for behaviour classification. For the purposes of this study, a flock was defined to include all Brolgas roosting and/or foraging within the study site during the study period and also all groups of 3 or more Brolgas observed at one site during field work. A nocturnal roost site was defined as a wetland where Brolgas were observed or heard (OZ Cranes 2008) at sunrise or sunset.

Sampling days commenced and concluded at nocturnal roost sites and involved continual observation of flock behaviour from dawn (or as early as possible thereafter) to dusk. When sampling days were commenced before sunrise, Brolgas were initially observed dispersing from roosts and then followed by vehicle. If Brolgas had already dispersed from the roost when sampling days commenced, flocks were located via systematic survey circuits of the study area. Sampling sessions were commenced once flocks had been located. Observations were carried out from a vehicle parked at least 100 m from flocks to minimise disturbance. Birds were observed directly using a Sky-Watcher 20-60 x 60mm Spotting Scope. Date, site, property, observation point, flock location, habitat type, cloud cover (clear/overcast) and stock presence (present/absent) were noted for each observation session. If it appeared that birds were engaging in vigilance behaviour (i.e. standing alert with head up and neck craned), suspected sources of disturbance were noted. It was also recorded if birds moved in or out of the visible area during a sampling session.
This project investigated patterns of Brolga behaviour and habitat use at the ‘patch’ scale. For the purpose of this study, a patch was defined as an area containing one specific habitat type where a flock of Brolgas was sighted during a sampling day, while the particular characteristics of the land within patches (e.g. pasture, freshwater wetland) were defined by the patch’s ‘habitat type’. Patch boundaries were somewhat arbitrary but were generally delineated by either the farm fences surrounding a field or the wetland perimeter, depending on habitat type within the patch. For analysis of time budgets, activity patterns, habitat use and ranges, it was assumed that use of a patch by a flock of Brolgas was directly related to the habitat type and/or location of the patch.

**Objective 1: Total bird numbers and recruitment rates**

The total number of birds within a flock was counted at the beginning and end of sampling sessions. Total bird numbers at each site were then determined from the maximum count for each sampling day and plotted on a scatter plot across the study period. The number of immature birds within a flock was also noted when visibility allowed. Immature birds can be distinguished from adults for at least the first 22 months of their lives by the absence of red head colouration (Arnol et al 1984; White 1987; Marchant and Higgins 1993). Recruitment rates were determined by dividing the proportion of immature birds by the total number of birds within the same flock. Recruitment rate estimates were tabulated across the study period for each site and presented in conjunction with recruitment rates obtained by DSE monitoring at the same sites in 2008.
Objectives 2 – 4: Collection of behaviour samples

This study made use of instantaneous scan sampling and timed focal animal sampling techniques for direct observation of Brolga behaviour (Altman 1974; Sutherland et al 2004; Morrison et al 2006). Instantaneous scan sampling involves systematically scanning a group of animals and classifying the behaviour of individuals at the instant when the individual is first observed (Sutherland et al 2004; Altman 1974). Focal sampling consists of watching an individual for a fixed period of time and recording its behaviour (Altman 1974; Sutherland et al 2004). Scan samples measure the distribution of behaviours within a flock at any one time while focal samples measure the relative amount of time allocated to different activities by a subsample of the flock.

The probability of detecting a particular behaviour during a scan sample is greater if that behaviour is performed more frequently throughout the day; therefore, the proportion of birds engaged in a behaviour is an indirect measure of the overall proportion of time that individual birds devote to that behaviour across the day. Similarly, the proportion of time that an individual devotes to different behaviours over the duration of a focal sample may be related to the amount of time allocated to that behaviour throughout the day. For the purposes of this study, it was assumed that the distribution of behaviours determined by both scan and focal samples would provide an index of the amount of time Brolgas allocated to different activities (e.g. feeding, resting) throughout the day. Time budget studies classify behaviours by way of a species’ ‘ethogram’, which is a set of functional definitions describing the species’ idiosyncratic body positions and their function. An ethogram was constructed from observations of Brolga
behaviour collected during preliminary visits to study sites. It was found that Brolga behaviour could be classified into the six categories shown in Table 2.1.

Table 2.1. Ethogram of Brolga behaviour classifications.

<table>
<thead>
<tr>
<th>Behaviour category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Up (HU)</td>
<td>Non-feeding, associated with either a neutral or vigilant state</td>
</tr>
<tr>
<td>Head Down (HD)</td>
<td>Stationary feeding/drinking</td>
</tr>
<tr>
<td>Walking (W)</td>
<td>Locomotive movement with head up</td>
</tr>
<tr>
<td>Searching (S)</td>
<td>Locomotive feeding/drinking with head down</td>
</tr>
<tr>
<td>Preening (P)</td>
<td>‘Comfort’ behaviour, associated with feather maintenance or scratching</td>
</tr>
<tr>
<td>Social (SC)</td>
<td>Interaction with other birds; courtship displays, mutual preening or aggressive encounters</td>
</tr>
</tbody>
</table>

Sampling sessions consisted of a series of flock counts and behaviour samples. The total number of birds and number of immatures (where possible) within the flock were counted initially, followed by an instantaneous scan sample of the entire flock. The duration of a scan sample was determined by the size and distribution of the flock (i.e. more birds = longer sample time). An individual bird was then selected for focal observation. Focal birds were selected haphazardly but were generally selected at regular distance intervals to avoid sampling bias due to position within the flock (Alonso and Alonso 1992). A focal bird was observed for up to three minutes while its behaviours were dictated to a Sansui MP3 Player. Birds were assumed to be adult unless otherwise noted (e.g. confirmed as immature or identification restricted by poor visibility). A focal sample was concluded if a focal bird went out of sight (e.g. behind trees) or flew away before 3 minutes had elapsed. Focal samples continued until approximately 10% of the flock had been sampled (Alonso and Alonso 1992). A second scan sample of the entire flock was then conducted to account for changes in flock behaviour which may have occurred in the duration of the sampling session. Sampling sessions were concluded with a final count of total
bird numbers and if possible, number of immatures within the flock, to account for any movement of birds in/out of the flock in during the sampling session.

Objectives 2 – 4: Statistical methods for behaviour analysis

Data collected from scan samples were arranged as separate variables measuring the proportion of birds within a flock engaged in each behaviour during each sample. Focal samples varied in duration due to focal birds often going out of sight during observation. Converting the number of seconds engaged in different behaviours to proportions of the original (‘raw’) focal sample duration would have inflated the magnitude of behaviours which occurred in short samples; for example, 3 seconds of foraging in a 10 second sample would give a higher proportion than 3 seconds of foraging in a 100 second sample. In order to prevent sample duration bias, focal samples were limited to 170 seconds (s), and samples shorter than this were discarded. Focal sample data were then arranged as separate variables measuring the proportion of time that the focal bird spent in different behaviours within a 170-s focal sample.

There were several issues associated with statistical analysis of behaviour samples. Firstly, behaviour samples were collected opportunistically according to flock movements so sample sizes were necessarily unequal between different factor levels. Also, behaviour data was obtained by repeatedly sampling the same birds (not individually distinguishable) at different patches and times, meaning that between-individual variation could not be accounted for by a repeated measures design. It was determined that these potentially confounding effects could be overlooked for the purposes of this exploratory study. Many behaviour variables were negatively skewed due to a high prevalence of zero counts, which is a common occurrence in time budget
studies (Dytham 1999). Thus parametric analyses (i.e. student $t$-test, single-factor analysis of variance) were performed when the assumptions of parametric tests were fulfilled. When these assumptions could not be met, non-parametric tests (i.e. Mann-Whitney $U$-test; Kruskal-Wallis $H$ test) were substituted. Normality of the distribution of behaviour variables was checked either with a one-sample Kolgorov-Smirnov test or a box plot of different factor levels. Homogeneity of variances was checked using a Levene’s test. Where assumptions were not met, an arcsine square root (angular) transformation (Dytham 1999) was applied to improve normality of distributions: $y_{ang} = 57.295 \cdot (\sin^{-1}\sqrt{y})$. Angular transformations have been noted where used as ‘ANG’ and the standard error of the mean (SE) was used to measure error.

**Objective 2: Time budget analysis**

Time budgets and foraging success measures were analysed using methods described in the above section. The dependent variable for this analysis was behaviour (6 levels; Table 2.1) and the independent variable was site (2 levels; Penshurst and Willaura). Time budgets were determined from the proportion of birds (scan samples) and proportion of time (focal samples) engaged in each behaviour over all times of day. The relative success of foraging efforts were investigated using two measures: i) the foraging success ratio, which was determined by dividing the number of birds engaged in active feeding (i.e. head down) by the total number of birds engaged in foraging activities (i.e. head down and searching for food); and ii) foraging efficiency, which was determined by dividing the proportion of time that focal birds were engaged in active feeding by the total proportion of time engaged in foraging activities. These foraging success measures were based on methods used by Alonso and Alonso (1992, 1993) in studies of Eurasian Crane foraging behaviour.
Objective 3: Activity patterns analysis

Activity patterns were analysed using statistical methods described above. The dependent variable for this analysis was behaviour and the independent variables were site (2 levels) and time of day (3 levels; Table 2.2). Time was recorded at the beginning of sampling sessions. As Brolga activity was thought to vary between morning/afternoon and midday (Arnol et al 1984); daylight hours were divided into three periods (Table 2.2). Activity patterns across sites were determined from the proportion of birds (scan samples) and proportion of time (focal samples) that birds engaged in each behaviour within each time of day.

Table 2.2. Factor level for activity patterns analysis.

<table>
<thead>
<tr>
<th>Time of day</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>6:00 am - 10:00 am</td>
</tr>
<tr>
<td>Midday</td>
<td>10:00 am - 2:00 pm</td>
</tr>
<tr>
<td>Afternoon</td>
<td>2:00 pm - 6:00 pm</td>
</tr>
</tbody>
</table>

Objective 4: Habitat use analysis

Habitat use was analysed using the statistical methods described above. The dependent variable for this analysis was behaviour (6 levels; Table 2.1) and the independent variables were site (2 levels) and habitat type (7 levels; Table 2.3). The patch habitat type was recorded at the beginning of sampling sessions. Brolgas utilised six habitat types shown in Table 2.3. Pasture habitats consisted of native and/or exotic grass species and were generally used for sheep grazing. Standing cereal crops at Penshurst were composed of wheat which had failed to reach harvest size, while at Willaura they were composed of a second-year germination of a harvested wheat crop which had been left fallow. Crop stubble fields (intact and burnt) at both sites were
generally wheat stubble of varying heights. Wetlands at Penshurst were exclusively modified permanent open freshwater while Willaura wetlands were exclusively semi-permanent salt pan. The extent of area covered by different habitat types (‘availability’) within the study sites changed over the course of sampling due to farming regimes and was not able to be controlled by the researcher. Seasonal patterns of habitat use were derived by determining the modal (most frequent) habitat type in which Brolgas were observed during each sampling day.

Table 2.3. Habitat types used by Brolgas at flocking sites.

<table>
<thead>
<tr>
<th>Site 1. Penshurst</th>
<th>Site 2. Willaura</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pasture</td>
<td>1. Pasture</td>
</tr>
<tr>
<td>2. Standing cereal crop (failed wheat)</td>
<td>2. Standing cereal crop (wheat/fallow)</td>
</tr>
<tr>
<td>3. Crop stubble</td>
<td>3. Crop stubble</td>
</tr>
</tbody>
</table>

**Objective 5: Range mapping**

The spatial requirements of Brolgas at flocking sites were estimated by recording the location of patches used by Brolgas during the study period and applying the Minimum Convex Polygon (MCP) method (Mohr 1947) whereby the outermost points of an animal’s distribution are connected to determine the area over which animals range. Patch location was recorded at the start of sampling session and later marked on 1:25,000 topographical maps. Flock locations throughout the day were then marked on study site maps generated using the DSE Catchment Information Mapper program. Ranges were calculated using the area markup tool and maximum distance from roost was calculated using the distance markup tool.
Results

Approximately 12 hours of behaviour sample recordings were collected over 95 observation hours during 16 days from April to July 2008 (Table 3.1). Ten hours of focal samples were initially collected (Penshurst: 4:08 h; Willaura 6:01 h) (Table 3.1); after standardisation of focal samples the final focal sample dataset comprised 8 hours of recordings (Penshurst: 3:24 h; Willaura: 4:39 h).

Table 3.1. Summary of data collected showing number of individual patches observed, number of different habitat types where Brolgas were recorded, observation hours (h) and duration of behaviour sample recordings per site.

<table>
<thead>
<tr>
<th>Date</th>
<th>No. patches</th>
<th>No. habitat types</th>
<th>Observation hours (h)</th>
<th>Recording hours (h)</th>
<th>Scan sample (h)</th>
<th>Focal sample (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penshurst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11-Apr</td>
<td>1</td>
<td>1</td>
<td>01:30</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19-Apr</td>
<td>2</td>
<td>2</td>
<td>10:16</td>
<td>1:02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-Apr</td>
<td>5</td>
<td>4</td>
<td>10:58</td>
<td>1:28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21-Apr</td>
<td>8</td>
<td>4</td>
<td>09:17</td>
<td>0:23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-May</td>
<td>15</td>
<td>3</td>
<td>10:18</td>
<td>0:53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11-May</td>
<td>8</td>
<td>2</td>
<td>02:14</td>
<td>0:25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-May</td>
<td>4</td>
<td>3</td>
<td>00:34</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-May</td>
<td>3</td>
<td>2</td>
<td>03:49</td>
<td>0:09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-Jul</td>
<td>6</td>
<td>3</td>
<td>02:43</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9 days</td>
<td>15</td>
<td>51:39</td>
<td>4:48</td>
<td>0:48</td>
<td>04:08</td>
</tr>
<tr>
<td>Willaura</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-Apr</td>
<td>3</td>
<td>3</td>
<td>05:28</td>
<td>1:30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26-Apr</td>
<td>9</td>
<td>5</td>
<td>11:03</td>
<td>1:58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27-Apr</td>
<td>10</td>
<td>5</td>
<td>10:49</td>
<td>1:31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28-Apr</td>
<td>4</td>
<td>3</td>
<td>06:06</td>
<td>0:49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15-May</td>
<td>3</td>
<td>2</td>
<td>03:51</td>
<td>0:37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-May</td>
<td>5</td>
<td>4</td>
<td>05:47</td>
<td>1:03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-May</td>
<td>2</td>
<td>2</td>
<td>00:27</td>
<td>0:06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-Jul</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7 days</td>
<td>16</td>
<td>43:31</td>
<td>7:43</td>
<td>01:34</td>
<td>06:01</td>
</tr>
<tr>
<td>Total no. sampled</td>
<td></td>
<td></td>
<td>16 days</td>
<td>31</td>
<td>6</td>
<td>95:10</td>
</tr>
</tbody>
</table>
**Objective 1a: Bird numbers**

Total bird numbers at each site were derived from the maximum flock count recorded each day of sampling as per Guzmán *et al* (1999). Mean bird numbers, determined from the maximum flock count over around 9 sampling days at each site, were higher at Penshurst (113 ± 59; *n* = 8) than at Willaura (65 ± 37; *n* = 9). Maximum daily counts at both sites tended to decrease over the study period as birds left flocking sites. By early July, almost all birds had left the two flocking sites (Figure 3.1).

![Figure 3.1](image.png)

**Figure 3.1.** Maximum number of birds recorded during sampling days at Penshurst and Willaura.
Objective 1b: Recruitment rates

Across sites, immature birds comprised on average $3.2 \pm 2.2\%$ of the total number of birds within flocks; mean recruitment rate was higher at Penshurst ($4.3 \pm 2.4\%$) than Willaura ($2.1 \pm 1.2\%$) (Table 3.2). There were no obvious trends in recruitment rates, however the highest estimates ($6.9\%$ and $7.5\%$ - Penshurst) were recorded midway through the study period, while the lowest estimates ($0.8\%$ - Willaura; $1.6\%$ - both sites) were recorded at the beginning and end (respectively) of the sample period (Table 3.2). The recruitment rate measures both first and second year birds, which means that it accounts for approximately twice the annual reproductive rate (Herring 2001). This suggests that annual reproduction is approximately $2\%$ for birds that flock at Penshurst and $1\%$ for birds that flock at Willaura.

Table 3.2. Recruitment rates recorded by DSE flocking site monitoring in 2008 (denoted *) and maximum recruitment rates recorded at Penshurst and Willaura during the study period.

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>March</th>
<th>Mid-April</th>
<th>Late April</th>
<th>Mid-May</th>
<th>Late May</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penshurst</td>
<td>4.1%*</td>
<td>1.9%*</td>
<td>7.5%</td>
<td>-</td>
<td>2.2 – 3.6%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Willaura</td>
<td>7.3%*</td>
<td>4.5%*</td>
<td>0.8%</td>
<td>1.4 – 4.3%</td>
<td>1.6 – 2.2%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>
Objective 2: Time budgets

The observed frequencies of most behaviours (except head up – scan samples) differed significantly from frequencies predicted by a random distribution (Table 3.3), thus birds allocated their time to different behaviours in a non-random way. During scan samples, 31 ± 2% of birds within flocks across sites were engaged in head down (i.e. actively feeding); 27 ± 2% were engaged in head up (i.e. scanning or resting); 16 ± 2% were searching for food; 14 ± 2% were walking (i.e. travelling between and/or within patches) and 12 ± 2% were engaged in preening (Table 3.3). Social interactions were not often observed at either site, with only 1% of flocks on average engaged in displaying, pair unison calls, aggressive encounters or mutual preening (Table 3.3). Across sites, birds spent 40 ± 3% of their time actively feeding, 20 ± 2% scanning or resting, 19 ± 2% searching for food, 13 ± 2% of time engaged in preening and only 8 ±1% of time travelling between and/or within patches (Table 3.3). Social interactions accounted for a very small proportion of time budgets (<0.01%) (Table 3.3) and therefore were not considered in further analyses.
Table 3.3. Summary of results of a) scan samples and b) focal samples showing sample sizes (n) and means ± standard errors of the mean. Chi-square values ($\chi^2$), degrees of freedom (d.f.) and significance values ($p$) compare frequencies of behaviour variables to frequency predicted by a random distribution.

<table>
<thead>
<tr>
<th>Proportion of flock</th>
<th>n</th>
<th>Mean ± SE</th>
<th>$\chi^2$</th>
<th>d.f.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head down</td>
<td>113</td>
<td>0.31 ± 0.02</td>
<td>92.885</td>
<td>54</td>
<td>0.001</td>
</tr>
<tr>
<td>Head up</td>
<td>113</td>
<td>0.27 ± 0.02</td>
<td>47.991</td>
<td>47</td>
<td>0.432</td>
</tr>
<tr>
<td>Preening</td>
<td>113</td>
<td>0.12 ± 0.02</td>
<td>536.301</td>
<td>36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Searching</td>
<td>113</td>
<td>0.16 ± 0.02</td>
<td>469.425</td>
<td>41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Social</td>
<td>113</td>
<td>0.01 ± 0.00</td>
<td>950.814</td>
<td>12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Walking</td>
<td>113</td>
<td>0.14 ± 0.02</td>
<td>238.69</td>
<td>38</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proportion of focal sample</th>
<th>n</th>
<th>Mean ± SE</th>
<th>$\chi^2$</th>
<th>d.f.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head down</td>
<td>167</td>
<td>0.40 ± 0.03</td>
<td>626.934</td>
<td>90</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Head up</td>
<td>167</td>
<td>0.20 ± 0.02</td>
<td>205.659</td>
<td>73</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Preening</td>
<td>167</td>
<td>0.13 ± 0.02</td>
<td>3082.754</td>
<td>46</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Searching</td>
<td>167</td>
<td>0.19 ± 0.02</td>
<td>1288.749</td>
<td>69</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Social</td>
<td>167</td>
<td>-</td>
<td>919.76</td>
<td>6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Walking</td>
<td>167</td>
<td>0.08 ± 0.01</td>
<td>2162.641</td>
<td>49</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Time budgets differed between sites for several behaviours. A higher proportion of birds were head down (ANG; $F_{1,112} = 4.069, p = 0.046$) and preening ($U = 1151; p = 0.024$) at Penshurst, while a higher proportion of birds were searching for food ($U = 904.5; p < 0.001$) at Willaura (Table 3.3). The proportion of flock engaged in other behaviours did not vary significantly between sites ($p > 0.05$). Time per focal sample engaged in head down ($U = 2325.5; p = <0.001$) and searching ($U = 1757.5; p = <0.001$) also differed significantly between sites. At Penshurst ($n = 74$), focal birds spent 52% of their time actively feeding while Willaura birds ($n = 93$) allocated only 30% of their time to feeding; in contrast, birds at Penshurst spent less time (7%) searching for food than Willaura birds (28%) (Table 3.3). Proportion of time per focal
sample engaged in other behaviours (head up, preening, walking) did not vary significantly between sites ($p = >0.05$). Thus Penshurst flocks spent less time searching for food and more time actually consuming food compared to Willaura flocks. However, when foraging-related activities (actively feeding and searching for food) are considered together, no significant difference is observed in the proportion of birds engaged in foraging activities between sites ($F_{1,112} = 1.212, p = 0.273$) or in the proportion of time allocated to foraging ($F_{1,165} = 0.48, p = .827$). Across sites, 50% of flocks were engaged in foraging-related activities and spent around 60% of time feeding or searching for food (Table 3.3).

The difference between sites in time spent feeding and searching for food suggests that birds at Willaura may have lower net intake rates than Penshurst birds and may therefore be food-limited. This may explain why a higher proportion of birds were engaged in preening (a comfort behaviour) at Penshurst ($U = 1151, p = 0.024$) (Table 3.3). This discrepancy is reflected in differences between sites in the foraging success ratio (proportion of birds actively feeding compared to proportion of all birds engaged in foraging activities) and foraging efficiency (proportion of time spent actively feeding compared to proportion of time engaged in foraging activities) (Figure 3.2). The foraging success ratio was significantly higher at Penshurst ($U = 750.5, p = <0.001$), with a mean of $80 \pm 4\%$ ($n = 50$) of foraging birds actively feeding at Penshurst compared to a mean of $56 \pm 4\%$ at Willaura ($n = 55$). Similarly, foraging efficiency was significantly higher at Penshurst ($n = 61$), where birds spent on average $80 \pm 4\%$ of foraging time actually feeding and $20 \pm 4\%$ on average searching for food. Willaura birds, in contrast, spent only an average of $54 \pm 4\%$ of foraging time actually feeding and an average of $46 \pm 4\%$ searching for food (Figure 3.2).
Figure 3.2. Mean foraging success ratio and mean foraging efficiency at Penshurst and Willaura. Note foraging success ratio = proportion of birds actively feeding to proportion of birds engaged in foraging activities; foraging efficiency = mean proportion of foraging time spent activity feeding. Error bars indicate standard errors.
Objective 3: Diurnal activity patterns

Activity patterns were found to differ between different times of day both across and between sites. Scan sampling indicated that the highest mean proportions of birds at Penshurst were actively feeding in the morning (63%) and afternoon (49%), while the lowest mean proportion (23%) were feeding at midday (Figure 3.3). The proportion of birds feeding at midday was significantly different to that recorded in the morning (ANG; Tukey’s HSD; mean difference (MD) = -19.75848, \( p = 0.016 \)) and in the afternoon (ANG; MD = -15.86185, \( p = 0.034 \)). Time of day did not influence the proportion of birds engaged in head up, searching or walking at Penshurst (\( p = >0.05 \)) (Figure 3.3). When all foraging-related activities are considered (i.e. feeding + searching for food), a higher proportion of birds at Penshurst were foraging in the morning compared to midday (ANG; MD = 18.47, \( p = 0.019 \)). In contrast, the proportion of birds preening in the morning was significantly lower than at midday (\( U = 82.50, p = 0.038 \)). Thus more Penshurst birds engaged in foraging in the morning and afternoon while more engaged in preening at midday, suggesting that Penshurst birds exhibit a bimodal distribution of feeding behaviour with an inverse pattern of preening. However, focal samples showed no significant difference between times of day in proportion of time engaged in any behaviour, including foraging-related activities (\( p = >0.05 \)) (Figure 3.4).

At Willaura, scan samples indicated that time of day had no effect on proportion of birds engaged in any behaviour (\( p = >0.05 \); Figure 3.3), however, focal samples showed Willaura birds spent more time searching in the afternoon compared to the morning (\( U = 222, p = 0.016 \)) and midday (\( U = 304, p = 0.002 \)) (Figure 3.4). Willaura birds spent less time engaged in head up in the afternoon compared to the morning (\( U = 200, p = 0.004 \)) and midday (\( U = 348.5, p = \))
0.012), and spent more time walking in the morning compared to midday ($U = 338, p = 0.016$). Time of day had no effect on proportion of Willaura birds engaged in foraging-related activities ($p > 0.05$), however, focal samples indicated that Willaura birds spent significantly more time foraging in the afternoon compared to morning ($U = 207.500, p = 0.007$) and midday ($U = 312.50, p = 0.003$) (Figures 3.3 and 3.4). Thus Willaura birds engage in the bulk of their foraging in the afternoon while spending more time walking between and/or within foraging patches in the morning. Time of day had no effect on mean foraging success ratio nor mean foraging efficiency at either site (KW, $p > 0.05$).

Flocks at Penshurst had a higher proportion of birds engaged in head down (t-test; $F_{2,47} = 1.573, p = 0.001$) and spent more time engaged in head down (t-test; $F_{2,54} = 5.115, p = 0.001$) in the morning compared to Willaura flocks, which had a higher proportion of birds engaged in head up at midday (t-test, $F_{2,47} = 0.452, p = 0.009$) (Figures 3.3 and 3.4). Willaura flocks had a higher proportion of birds engaged in searching across all times of day and spent more time searching across all times of day ($p < 0.05$). Mean proportion of time spent walking in the morning was also significantly higher at Willaura (t-test; $F_{2,54} = 38.773, p = 0.035$) There were no between-site differences in proportion of flock engaged in preening within different times of day ($p > 0.05$) (Figures 3.3 and 3.4).
Figure 3.3. Mean proportion of flock engaged in head down (HD), head up (HU), preening (P), searching (S) and walking (W) at Penshurst (above) and Willaura (below) by time of day. Note morning = 6:00 am to 10:00 am; midday = 10:00 am to 2:00 pm; afternoon = 2:00 pm to 6:00 pm. Error bars indicate standard errors.
Figure 3.4. Mean proportion of time per 170 s focal sample engaged in head down (HD), head up (HU), preening (P), searching (S) and walking (W) at Penshurst (above) and Willaura (below) by time of day. Note morning = 6:00 am to 10:00 am; midday = 10:00 am to 2:00 pm; afternoon = 2:00 pm to 6:00 pm. Error bars indicate standard errors.
Objective 4: Habitat use

Flocks were recorded in 6 different habitat types during the study period. Four of these – pasture, standing cereal crop, cereal crop stubble and burnt stubble – occurred at both sites in varying proportions, while wetlands at Penshurst ($n = 5$) were exclusively permanent freshwater and those at Willaura ($n = 3$) were semi-permanent salt-pan. Scan samples were collected at the start of an observation sessions, which were initiated when flocks were encountered for the first time of the day or after flocks moved to a different patch. The proportion of habitat types within which scan samples were collected therefore reflects the relative frequency of use of different habitat types. Sampling effort for both sites was similar but not equal.

Brolgas changed their relative use of different habitat types in response to farming regimes at each site. At the onset of the study period, habitat types within study sites consisted of sheep pasture and crop stubble, with a higher relative proportion of pasture at Penshurst and a higher relative proportion of stubble at Willaura. Stubble habitats at both sites were then burnt in late April. In early April, birds were most often found in stubble crops; after burning, birds at each site foraged on burnt stubble fields however Penshurst birds also made heavy use of pasture while Willaura birds were often recorded feeding in a standing wheat crop. Some grain was retained in stubble fields after burning, and birds at both sites utilised burnt stubble habitats during the study period. A flock at Penshurst was observed to forage in a stubble field within hours of burning. By May, Penshurst birds foraged almost exclusively in pasture while Willaura birds relied heavily on the remaining standing wheat crop.
Behaviour patterns within different habitat types differed between sites. Penshurst birds spent more time actively feeding in pasture habitats ($t_{34.8} = 3.362, p = 0.002$) and burnt crop stubble ($t_{35} = 4.731, p = <0.001$) than birds at Willaura and had a higher proportion of birds feeding in crop stubble ($t_{4.8} = 4.414, p = 0.008$) and burnt stubble ($t_{23} = 2.132, p = 0.044$) (Figures 3.5 and 3.6). Willaura flocks had a higher proportion of birds engaged in searching ($t_{18.7} = -4.585, p = <0.001$) and spent more time searching ($t_{34.9} = -7.618, p = <0.001$) and walking ($t_{16.5} = -2.560, p = 0.021$) in burnt stubble (Figures 3.5 and 3.6). In wetlands (P: freshwater; W: saltpan), Penshurst birds spent more time actively feeding and/or drinking ($t_{20.9} = 4.077, p = 0.001$) while Willaura flocks had a higher proportion of birds searching for food ($t_{26.3} = -2.273, p = 0.031$) and spent more time engaged in head up ($t_{17.3} = 2.672, p = 0.016$) (Figures 3.5 and 3.6). Between-site differences in behaviour within standing cereal crops were not analysed statistically due to highly unbalanced sample sizes.

At Penshurst, proportion of birds engaged in head down differed significantly between pasture and stubble ($U = 5.0, p = 0.006$). The highest proportions of birds were feeding in crop stubble (75 ± 7%) and burnt crop stubble (47 ± 8%), where birds also allocated the highest proportion of time to feeding (68 ± 6% and 86 ± 7%, respectively) (Figures 3.5 and 3.6). Proportion of birds and proportion of time engaged in head up was similar across habitat types (around 20%) while searching was performed in low proportions and for short durations (<11%) across all habitat types. Proportion of birds and proportion of time engaged in preening was highest in pasture (around 20%) and wetlands (15%) (Figures 3.5 and 3.6). .
At Willaura, focal samples indicated significant differences between habitat types in proportion of time engaged in head down ($\chi^2_4 = 24.106, p < 0.001$), head up ($\chi^2_4 = 11.203, p = 0.024$), preening ($\chi^2_4 = 18.608, p = 0.001$) and searching ($\chi^2_4 = 18.767, p = 0.001$). Time spent actively feeding differed most significantly between habitat types, with proportion of time engaged in head down significantly lower ($p < 0.05$) in pasture (8 ± 3%) and wetland (12 ± 5%) when compared to crop habitats i.e. standing crop (39 ± 4%), stubble (50 ± 9%), and burnt stubble (29 ± 3%) (Figures 3.5 and 3.6). Proportion of birds searching was also higher in standing cereal crop ($U = 47.00, p = 0.006$) and burnt stubble ($U = 65.0, p = 0.018$) when compared to wetlands. Preening was mainly performed in pasture (around 30%) and wetlands (around 25%) and proportion of birds engaged in preening was significantly higher in pasture compared to burnt stubble ($U = 22.0, p = 0.016$) (Figures 3.5 and 3.6).

Between-habitat differences in foraging-related activities and preening were observed at both sites, suggesting that crop habitats are used predominantly for foraging while wetlands (freshwater and saline) are used for comfort behaviour such as preening. Mean foraging success ratio and mean foraging efficiency did not vary between habitats at Penshurst. At Willaura, the foraging success ratio was not influenced by habitat however focal samples indicated that foraging efficiency in crop stubble was significantly higher than in standing crop ($U = 63.0, p = 0.017$) and burnt stubble ($U = 66.0, p = 0.004$). Thus crop stubble may constitute the most significant foraging habitat for birds at Willaura.
Figure 3.5. Mean proportion of flock engaged in head down (HD), head up (HU), preening (P), searching (S) and walking (W) at Penshurst (pale grey) and Willaura (dark grey) by habitat type. Error bars indicate standard errors.
Figure 3.6. Mean proportion of time per 170 s focal sample engaged in head down (HD), head up (HU), preening (P), searching (S) and walking (W) at Penshurst (pale grey) and Willaura (dark grey) by habitat type. Error bars indicate standard errors.
Objective 5: Ranges

The maximum distance from roost recorded at Penshurst was approximately 5.5 km and total range over the study period was 18.8 km². Average distance from roost at Penshurst was 1.9 ± 0.3 km (Figure 3.7).

Figure 3.7. Map of Penshurst study site showing roost location, location of patches where Brolgas were recorded (red stars), location of patch at maximum distance from roost where Brolgas were observed (black line) and daily range as determined by the minimum convex polygon method (red line).
Foraging flocks at Willaura covered considerably less area than those at Penshurst; here, maximum distance from roost was approximately 2.3 km and total range over the study period was 3.6 km\(^2\). Average distance from roost at Willaura was 1.6 ± 0.2 km (Figure 3.8).

Figure 3.8. Map of Willaura study site showing roost location, location of patches where Brolgas were recorded (red stars), location of patch at maximum distance from roost where Brolgas were observed (black line) and daily range as determined by the minimum convex polygon method (red line).
Discussion

Bird numbers

The total number of birds at each site was similar early in the flocking season, however after mid-April numbers at Penshurst increased while those at Willaura concurrently decreased. This shift was also observed mid-season in 2007 (P. Du Guesclin, pers. comm.). Until recently, Penshurst was not considered to be a major flocking site, however over the past few decades the number of birds at this site appears to have increased by a factor of five (J. Ritchie, A. Rentsch, pers. comm.). This site, previously unknown to managers, represented the most heavily used flocking site in south-west Victoria during the 2007-08 flocking season.

The number of Brolgas recorded at Willaura, which is considered to be the major flocking site within the study area (Arnol et al 1984; White 1987), was slightly lower in 2008 than previously recorded. Numbers at Willaura and at sites in northern Victoria have varied by a factor of three to four over several years (Herring 2001). Interannual site dynamism is likely to be due to a variable proportion of birds remaining at breeding sites over the flocking season, which is in turn related to rainfall variation which determines breeding site availability (Herring 2001). However, the decrease in numbers at Willaura and concurrent increase at Penshurst in April 2008 suggests that use of flocking sites may also vary within years in response to changes in site suitability. Wetlands at Willaura have been less permanent in recent years, with uncharacteristic drying up over the flocking season (R. Hill, pers. comm). Considering that roost site availability is likely to be an important limiting factor for Brolgas during the flocking season, the lack of available
wetlands at Willaura may in part explain the reduction in numbers observed at this site within the 2007 and 2008 flocking seasons.

The possible effects of human-induced climate change on Australia’s wetland bird species are still unclear however modeling studies have projected a widespread decline in wetland availability in southern Australia if average annual temperatures rise (Chambers 2007; Sutherst et al 2007). Considering the importance of permanent flocking season wetlands to Brolgas in southern Australia, the Brolga could be significantly impacted by the effects of climate change. The changes in wetland availability at Willaura in 2007 and 2008, in addition to the reduction in Brolga numbers observed midway through the flocking season and the concurrent increase at Penshurst (where wetlands remained permanent) tend to suggest that Brolgas in southern Australia may already be experiencing impacts from changes in climate. The status of the population should be monitored closely in future to determine any potential climate change related impacts (Sutherst et al 2007).

**Recruitment rates**

Previous recruitment rate estimates for the southern Brolga population are generally around 4 – 5% (Herring 2001). Across the study period, the mean recruitment rate was estimated at 4.3 ± 2.4% at Penshurst and 2.1 ± 1.2% at Willaura. However, the maximum proportion of immatures recorded at each site were much higher than these estimates (7.5% and 4.3 % respectively). The maximum recruitment rate for Penshurst was high compared to recent estimates for other south-west Victorian sites, while estimates recorded at Willaura were consistently lower than reported for this site by White (1987) (10%), Pizzey (1994) (28%) and Sheldon (2004) (10%). The high
figure recorded by DSE at Willaura in January is similar to that recorded at Penshurst in mid-April; this sharp change in immature bird numbers occurred concurrently with the mid-season change in overall numbers at each site (Section 4.1.). It is possible, therefore, that the observed change in recruitment rates may be the result of Brolga families migrating from Willaura to Penshurst.

Recruitment estimates for the southern Brolga population are consistently lower than estimates reported for the northern population; for example, immature birds comprised 17% of flocks censured in northern Queensland from 1968 – 1970 (Sheldon 2001) and at least 20% of birds flocking in northern Western Australia (Herring 2001). This supports the belief that an aging reproductive cohort in southern Brolgas may be contributing to demographic malfunction. Herring (2001) suggested that low recruitment rates may be sufficient to maintain a viable population if Brolgas remain fertile for 50 years; while longevity in wild birds is unknown, the oldest recorded age is 41 years in a (still living) captive bird (Veyret 2006). Numbers of Australian waterbirds are thought to vary in line with seven years drought cycles (Weller 1999). Climate-related reproductive fluctuations have also been recorded in Sandhill Cranes (Drewien et al 1996). Therefore it is likely that Brolga recruitment rates fluctuate with the rainfall variation which determines availability of breeding wetlands (White 1987; Herring 2001; Sheldon 2004).

The large range of recruitment estimates may be associated with differential habitat use, observability of flocks and observer experience, and caution should be used when interpreting estimates (Allan 1996; Grant 2005). DSE monitoring of study sites from January to April 2008 obtained consistently lower estimates for Penshurst and higher estimates for Willaura than
recorded during the present study. Brolga recruitment rates are difficult to measure from observation alone and are variable between observers (Herring 2001; Sheldon 2004). This poses difficulty for managers in assessing the status of the south-west Victorian population, which is compounded by the fact that birds that stay at breeding sites year-round are not accounted for in flocking site censuses (White 1987; Sheldon 2004).

**Time budgets and activity patterns**

Brolgas across sites allocated most of their time (approximately 60%) to foraging-related activities (feeding and searching for food). This is similar to estimates reported for Eurasian Cranes (Alonso and Alonso 1993; Aviles 2003), White-naped Cranes (Lee et al. 2007a, 2007b; Bradter et al. 2007) and Red-crowned Cranes (Lee et al. 2007a, 2007b). Cranes tend to leave the roost within an hour of sunrise and return within an hour of sunset (present study; Walkinshaw 1973; Alonso and Alonso 1985; Sugden et al. 1988; Herring 2001), thus Brolgas, like other cranes, are active for the maximum amount of daylight regardless of location, and the proportion of time allocated to foraging therefore reflects the inherent behavioural adaptations of cranes which help to optimise foraging opportunity (Alonso and Alonso 1985, 1992).

The relative success of foraging effort is related to habitat quality and resource distribution (Alonso and Alonso 1985, 1992; Agetsuma and Nakagawa 1998). Penshurst birds spent a higher proportion of time actually feeding while Willaura birds spent more time searching for food. This is reflected by the foraging success ratio and mean foraging efficiency (both of which were higher at Penshurst), which indicate that birds at Penshurst had higher gross intake rates than birds at Willaura. Penshurst birds exhibited distinct peaks in foraging behaviour in the morning.
and afternoon, with a peak in preening behaviour at midday, however this pattern was not found at Willaura.

The variance-sensitive optimal foraging model proposes that animals are sensitive to variability in resource distribution and can change their foraging strategies accordingly to meet a threshold energy intake rate (Caraco 1979; Stephens and Krebs 1986; Alonso and Alonso 1992). Animals may select less variable patches of lower quality when their energy balances are negative – for example, early morning when nocturnal thermoregulatory costs must be recovered (variance-prone); alternatively, patches which offer more variably distributed food of high quality may be selected when threshold energy costs have been met – for example, late afternoon after a day of foraging (variance-averse) (Caraco 1979; Stephens and Krebs 1986; Alonso and Alonso 1992). Eurasian Cranes have been shown to exhibit intensive, variance-prone foraging in the morning and extensive, variance-averse foraging in the afternoon when inhabiting flocking sites of high habitat quality (Alonso and Alonso 1992). Variance-sensitivity may explain the two-peaked (bimodal) diurnal foraging patterns observed in Brolgas at Penshurst.

Bimodal activity patterns decline when intake rates are limited by available foraging time, high energetic costs or poor food availability (Aviles 2004; Li and Rogers 2004). For example, parental cranes have less time available for foraging due to the higher vigilance costs associated with parental investment (i.e. heightened need for vigilance due to predation risk for vulnerable offspring) (Alonso and Alonso 1993; Bradter et al. 2007). This time-limitation is reflected in changes in activity patterns, whereby foraging is performed at a constant rate across all times of day, with no period of midday comfort behaviour (Alonso and Alonso 1993; Bradter et al. 2007).
Birds at Willaura tended to forage at a steady rate across the entire day with no increase in preening at midday. Thus the absence of bimodal foraging peaks at Willaura may indicate that birds here are food and/or time limited compared to Penshurst birds.

Roost site selection

The nocturnal roost's role as a central point from which foraging movements are coordinated dictates that roost selection can have important implications for body condition and fitness. Eurasian Cranes (Alonso and Alonso 1985, 1992) and Sandhill Cranes (Sugden et al 1988) minimise energetic travel costs by selecting nocturnal roosts close to foraging areas. Energy balance is less likely to be a major concern for non-migratory Brolgas which flock on permanent wetlands during the driest months of the year. In south-west Victoria, rainfall and availability of surface water is more likely to be the major factor in roost site use (Sheldon 2004). Furthermore, in years of below average rainfall when permanent wetlands may become more ephemeral, roost site use is likely to be a function of availability rather than selection (Sheldon 2004). This was evident at Willaura, where Brolgas were observed to roost nocturnally on the only wetland (of three) which retained water throughout the study period. At Penshurst, Brolgas roosted nocturnally in just one of five available permanent freshwater wetlands, suggesting that availability was not the only determinant of use.

Roosts at both sites had water depths <0.5m and were located in areas where disturbance (e.g. from livestock, farm activities or road traffic) was low. It may be that the roost site at Penshurst offered greater protection from disturbance than other wetlands at the site, most of which were in areas which experienced a higher degree of human activity. Brolgas, like other cranes, can
acclimate to livestock and farm machinery however they are thought to be sensitive to
disturbance at flocking sites (Sugden et al 1988; Bautista et al 1992; Alonso et al 1994; Pizzey
1994; Herring 2001; Aviles 2003; Sheldon 2004; Bradter et al 2007). It appeared that roost site
selection among Penshurst birds was based on buffering from disturbance while at Willaura
selection was probably based on availability.

The availability of shallow, protected, permanent roost sites (freshwater or saline) is important
for Brolgas during the flocking season (Arnol et al 1984; White 1987; Herring 2001; Sheldon
2004). Sheldon (2004) noted that suitable roost wetlands were limited within south-west Victoria
and attributed the flocking behaviour of Brolgas to aggregation on remaining permanent
wetlands. Sheldon’s (2004) argument is supported by the fact that bird numbers at flocking sites
decline in years where higher rainfall increases the retention time of breeding wetlands.
Furthermore, White (1987) found that in years of good rainfall, some Brolgas may remain at
breeding territories year-round. Similarly, Eurasian Cranes will forgo flocking behaviour to
maintain family territories if sufficient suitable habitats remain available during the flocking
season. The availability of suitable roost sites is likely to be reduced in years of below-average
rainfall; furthermore, the permanent wetlands used by Brolgas for nocturnal and secondary
roosting typically occur on private land in south-west Victoria, and are therefore most vulnerable
to drainage and modification. Management of Brolga flocking habitat in south-west Victoria
should provide incentives for the protection and restoration of suitable roost wetland habitats on
private land (Herring 2001; Sheldon 2004).
Secondary roosts and comfort behaviour

Across sites, Brolgas spent about 15 – 25% of their time preening. This is similar to estimates reported for non-parental Eurasian Cranes (15%; Alonso and Alonso 1993) and non-parental White-naped Cranes (24%; Bradter et al 2007). Preening at Penshurst most frequently occurred in non-nocturnal (‘secondary’) roost wetlands. The use of secondary roosts for diurnal comfort behaviour has been observed in Eurasian Cranes (Johnsgard 1983), Sandhill Cranes (Sugden et al 1988) and White-naped Cranes (Bradter et al 2007). Birds at Penshurst also used secondary roosts for feeding and drinking. These wetlands had permanent regimes which provided fresh water throughout the flocking season and contained some emergent vegetative cover which presumably enhanced their foraging value. Brolgas at Willaura sometimes visited dry wetlands where they stood with head up for up to an hour. It is possible that this head-up behaviour constituted loafing activities however the behaviour was observed infrequently and in no clear pattern.

Birds at both sites drank from sheep troughs however Willaura birds obtained water exclusively from troughs as most wetlands here were dry for the bulk of the study period. The only major wetland at Willaura to remain wet throughout the study period was used regularly for roosting but rarely for foraging, and never for drinking. Sheldon (2004) found that Brolgas at south-west Victorian flocking sites frequented both freshwater and saline wetlands but did not distinguish between roosting (nocturnal and diurnal), drinking and foraging sites. It was previously unclear whether Brolgas drank from non-fresh water sources; the results of the present study suggest that saline wetlands may be utilised for roosting and foraging but not drinking, despite the fact that Brolgas possess a physiological adaptation for extrarenal salt section that is unique among cranes.
(Hughes and Blackman 1973). Studies in granivorous birds have shown that birds experience a period of negative water balance (i.e. near-dehydration) around midday and must move to water sources to rehydrate (MacMillen 1990; Alonso and Alonso 1992).

Foraging behaviour and habitat variability

Cranes often exhibit a preference for natural foods over agricultural food items (Shields and Benham 1969; Guthery 1975; Sugden et al 1988); for example, Brolgas flocking at the relatively intact Bool Lagoon in South Australia forage primarily on wetland tubers, invertebrates and small vertebrates (Sheldon 2004). However, when natural habitats are not available, cranes are able to exploit newly-available resources. This adaptability is reflected by seasonally variable habitat use patterns within flocking sites (Bautista et al 1992, 1995; Alonso et al 1994; Diaz et al 1996; Ballard and Thompson 2000; Aviles et al 2002; Stillman et al 2002; Aviles 2004). Eurasian Cranes arriving at wintering grounds in Iberia initially feed on widely available cereal stubble and progress to sown fields as stubble residue is depleted (Alonso and Alonso 1993). Similar habitat use plasticity is exhibited in Sandhill Cranes (Reinecke and Krapu 1986; Sugden et al 1988; Krapu et al 2004) and White-naped Cranes (Bradter et al 2007). Temporally variable habitat use in Brolgas at south-west Victorian flocking sites was noted (but not discussed) by Sheldon (2004).

Brolgas at Penshurst and Willaura exhibited habitat use plasticity in response to farming regimes. Early in the study period, the major foraging habitat type at both sites was crop stubble, and Brolgas foraged in these fields even when stubble was burnt in mid-April. Later in the study period, when grain density in burnt fields was presumably depleted (Alonso and Alonso 1993),
birds at Penshurst were found more frequently in pasture fields while Willaura flocks were recorded more often in standing wheat. This behaviour reflected the relative availability of the different habitat types at each sites. Thus it appears that Brolgas are capable of responding to temporal habitat variation that occurs during the flocking season and are not locked into non-adaptive ‘traditional’ behaviour patterns (Arnol et al 1984).

**Diets and the importance of agricultural foods**

For many crane species, proximity to grazing and cropping land is now considered to be an important determinant of flocking site selection (Guthery 1975; Bautista et al 1992; Alonso et al 1994; Allan 1995; Meine and Archibald 1996; Guzman et al 1999; Aviles et al 2002; Krapu et al 2004). Across the entire study period, Brolgas at both Penshurst and Willaura spent the highest proportion of time actively feeding when they were in cereal stubble, burnt stubble and standing cereal crop, in descending order. The preference for crop fields observed in flocking cranes is likely due to the high energy content of crops such as wheat, triticale, barley, corn and rice (Johnsgard 1983; Reinecke and Krapu 1986; Guzman et al 1999; Ballard and Thompson 2000; Aviles et al 2002; Krapu et al 2004). Cranes living in natural habitats forage heavily on the tubers of wetland plants (Johnsgard 1983; Meine and Archibald 1996), so in the absence of natural grasslands and wetlands with intact vegetative assemblages, crop lands constitute an important substitute for natural energy-dense food items (Guthery 1975; Iverson et al 1987; Ballard and Thompson 2000; Krapu et al 2004).

The net energy yield of food items is determined in part by the relative handling/searching time associated with obtaining food. For example, net energy yield is higher in stubble habitats where
grain occurs on the soil surface than in standing crops where grain is more difficult to detect (Alonso and Alonso 1992, 1993; Lee et al 2007). Higher net energy yield due to lower handling/searching times may explain a preference for stubble habitats over standing crops in Canadian Sandhill Cranes (Sugden et al 1988), and may be why Brolgas at Willaura spent a higher proportion of time actively feeding in stubble habitats (intact and burnt) compared to standing wheat, which was available throughout the study period. This reliance on crop foods was not observed by Sheldon (2004), possibly because within-site habitat use patterns were not investigated during that study and crop land is less abundant within south-west Victoria compared to grazing land (GHCMA 2003). This is evidenced by the fact that all 29 sites investigated by Sheldon (2004) were surrounded by crop and/or grazing land but never grazing land alone.

Brolgas at Penshurst and Willaura also foraged in pasture (often alongside sheep) and appeared to be feeding mainly on non-grain items which had to be pierced or dug up. Proximity to grazing land is thought to be an important factor in Brolga flocking site selection (White 1987; Herring 2001; Sheldon 2004). Crane researchers have speculated that a range of animal food items traditionally sourced from natural grasslands and wetlands are now sought in pasture and other non-crop fields (Reinecke and Krapu 1986; Allan 1995; Ballard and Thompson 2000, Krapu et al 2004). Brolgas are known to forage for invertebrates and small mammals and reptiles in natural grasslands of northern Victoria (Herring 2001). Cranes foraging in pasture have a higher intake of annelids, molluscs (live and empty shells) and small vertebrates than those foraging in crop land (Reinecke and Krapu 1986; Allan 1995; Ballard and Thompson 2000; Krapu et al 2004). Animal food items contain a higher proportion of calcium and a larger range and
proportion of essential amino acids than vegetable material (Reinecke and Krapu 1986; Aviles et al 2002). Reinecke and Krapu (1986) demonstrated the importance of calcium and amino acids in the diet of Nebraskan Sandhill Cranes, which spent the same proportion of time searching for invertebrates (which composed 3% of the diet) as they did searching for corn residue (97% of the diet).

Pasture-foraging cranes may benefit from the presence of livestock through enhanced soil organic content (by action of their manure) and increased abundance of invertebrate prey species (Reinecke and Krapu 1986). Several focal birds at Penshurst were recorded stabbing at cow pats, presumably to acquire the invertebrates within. This behaviour which has also been observed in Sandhill Cranes (Reinecke and Krapu 1986) and Eurasian Cranes (Aviles et al 2002). Diet composition was not investigated in this study, however diets of captive Brolgas usually include carbohydrates (e.g. wheat grain), protein (e.g. turkey mince) and calcium (layer pellets) (Veyret 2006; M. Helman, pers. comm.), illustrating the importance of a balanced diet for body condition and fitness. A range of amino acids (the main component of protein) obtained from animal foods is essential for growth and maintenance of cranes of all age classes (Serafin 1982; Reinecke and Krapu 1986; Sugden et al 1988; Guzman et al 1999; Aviles et al 2002). Calcium, obtained from crustacean shells and exoskeletons, is likely to be an important component of pre-breeding season diets for egg-laying (Serafin 1982), as evidenced by the tendency of Sandhill Cranes to dig up and ingest lime nodules from the soil during the flocking season (Reinecke and Krapu 1986).
**Spatial requirements**

The extent of an animal’s home range is determined by the quality and distribution of habitat features (Mysterud and Ims 1998; Agetsuma and Nakagawa 1998). Cranes limited by food and/or time in areas of low habitat quality tend to exhibit smaller ranges (Starling and Krapu 1994). Energy-limited Eurasian Cranes arriving at flocking sites after post-Summer migration initially minimise energetic travel costs by foraging at patches closer to the roost, irrespective of patch quality. As energy stores are replenished, cranes seek to exploit higher quality patches by progressively increasing the size of daily ranges (Alonso et al 1987; Bautista et al 1995; Aviles et al 2002). Similarly, daily ranges were smaller in time-stressed (and thereby food-limited) White-naped Cranes (Bradter et al 2007).

The ranging behaviour of cranes is consistent with the foraging model proposed by Norberg (1977), which predicts that food and/or time-limited animals minimise energetic costs by limiting ranges and foraging more heavily within a core area. Birds at Penshurst used a larger foraging area than Willaura flocks (18.8 km² compared to 3.6 km² respectively) and had a higher maximum distance from roost than birds at Willaura (5.5 km compared to 2.3 km respectively). Herring (2001) found Brolga flocks to forage within an area of 200 – 1000 ha at distances usually 1 km but up to 5.2 km from nocturnal roosts. The observed discrepancy in ranges between sites indicates that Willaura birds were more food and/or time-limited than those at Penshurst. This, in addition to the differences in foraging efficiency, activity patterns and comfort behaviour, further indicates that the new Penshurst site may fulfill the habitat requirements of flocking Brolgas better than the traditional Willaura site. Ranges estimated during the present study are considered conservative, as the area over which flocks could be
observed was determined by the number of accessible properties; on several occasions, small
groups of Brolgas at Willaura were observed dispersing from the roost in the morning but were
not located during survey circuits. Thus the true extent of spatial requirements during the
flocking season is still unclear.

**Habitat complexity and flocking site selection**

Flocking site selection in cranes is likely to be related to a site’s ability to provide a range of
important habitat features (foraging, drinking, loafing and sleeping sites) distributed in such a
way as to minimise energetic costs. Iverson *et al* (1987) determined that suitable Sandhill Crane
habitat included a river roost site, agricultural lands comprising roughly two-thirds corn stubble
and one third pasture, and several secondary roost sites located within 4 km of the nocturnal
roost. The positive role of habitat heterogeneity in individual bird fitness is well known
(Mysterud and Ims 1998). Heterogeneity can also serve to buffer cranes against the loss of
foraging resources due to farming regimes and food depletion (Allan 1995; Alonso *et al* 1995;
Ballard and Thompson 2000; Aviles *et al* 2002).

Cranes are known to move to non-traditional sites in response to changes in habitat quality
(Johnsgard 1983; Arnol *et al* 1984). If it is assumed that flocking site selection in Brolgas is
partly dynamic rather than strictly traditional (Herring 2001; Sheldon 2004), bird numbers at
flocking sites may be expected to fluctuate both between and within years. This pattern was
indeed observed during the present study, suggesting that Brolgas are capable of responding to
changes in flocking site suitability and relocating accordingly.
Dispersal between breeding and flocking sites is not well understood due to the difficulty of tracking unmarked birds. The findings of the present study indicate that Brolgas may also disperse between flocking sites during the flocking season. Like other cranes, Brolgas are capable of undertaking long-scale migrations over days and months (Westerskov 1968). If within-season migration between sites is indeed occurring, there is the potential for migrating birds to encounter barriers such as powerlines and other large infrastructure. Such structures are known to impose barrier effects on migrating birds by blocking flight paths, increasing energetic travel costs and causing direct mortality via collisions (Goldstraw and Du Guesclin 1991; Janss and Ferrer 2000). Janss and Ferrer (2000) investigated powerline collisions in Eurasian Cranes and estimated a mortality rate of 0.3 birds killed for every 100 birds crossing, while several Brolga mortalities have been attributed to collisions with aircraft (ATSB 2003) and powerlines (Goldstraw and Du Guesclin 1991).

Any large infrastructure developments (e.g. wind turbines) which are proposed for the areas around and between flocking sites should take into account the potential impact of barrier effects on the threatened southern population. Flight paths, dispersal patterns and spatial requirements throughout the entire annual cycle could be elucidated with the use of satellite tracking techniques, which have provided great insight into landscape-scale habitat use patterns in crane species such as Siberian (Kanai et al 2002), White-naped (Fujita et al 2004; Higuchi et al 2004) and Eurasian Cranes (Alonso and Alonso 1992, 1993; Alonso et al 1995).
Management issues

Appropriate management of wildlife habitat is contingent upon an adequate understanding of population parameters and habitat use variability (spatial and temporal) (Krebs 1994). When studying highly mobile bird species, it may be beneficial to sample at several points throughout the season (Bautista et al 1992), which is the logic underlying monthly DSE censuses of Brolga flocking sites in Victoria. However, due to the dispersal of foraging flocks around sites at the time of censuring, data can be highly variable. During the study period, the highest numbers were recorded at nocturnal roosts early in the morning and at secondary roosts at midday. Alonso and Alonso (1992) also found flock size in Eurasian Cranes to be greatest at roost sites. Thus it is recommended that flocking site censuring be conducted at known secondary roost sites around midday to ensure that the majority of birds are accounted for. This may help to reduce the observed variability in monthly census numbers and provide more accurate estimates of recruitment rates.

The scale at which populations are studied affects the detection of relationships between habitat features and habitat use patterns (Morrison et al 2006). Sheldon (2004) assessed flocking site use in Brolgas at the landscape scale but conceded that factors contributing to site selection were unclear. It is proposed that the apparent variability noted by Sheldon (2004) is the result of habitat use patterns operating at the within-site scale, which the present study sought to investigate. It is apparent that flocking sites are highly variable, as even the two most heavily used south-west Victorian sites differed significantly in habitat quality and resource distribution. Furthermore, habitat types within study sites varied temporally and spatially and were used for different purposes by Brolgas. The distribution and availability of habitat features at other
flocking sites in south-west Victoria were not assessed however it could be expected that these sites exhibit similar variability. It is therefore important that managers recognise and account for between-site differences in habitat use patterns when attempting to manage Brolga flocking habitat. The potential for climate change to affect the availability of suitable roost sites and the possible impact on Brolgas at flocking sites should be investigated, with ongoing monitoring of population parameters (Sutherst et al 2007).

Study limitations and recommendations for further research

General time and funding constraints limited the number of samples collected and the period over which field investigations were conducted, resulting in unbalanced sample sizes and potential problems with statistical analysis. Field work was commenced midway through the Brolga flocking season, precluding opportunities to assess seasonal patterns. Furthermore, this study necessarily made several assumptions about Brolga behaviour (e.g. feeding time and food intake rate are directly related) and habitat quality (e.g. Brolgas select different patch types based on nutritional needs) based on previous studies of habitat use in cranes. In some cases it has been demonstrated that the time spent engaged in foraging is not necessarily linearly related to intake rates (Alonso and Alonso 1992; Morrison et al 2006).

More intensive and long-term sampling across the entire flocking season could better elucidate behaviour and habitat use in flocking Brolgas. Long-term studies of Eurasian Cranes wintering in southern Europe (Alonso and Alonso 1992, 1993; Alonso et al 1995; Bautista et al 1992, 1995; 1999) have revealed an enormous amount of complexity in habitat use dynamics which cannot be detected with simple time budget techniques. These studies have benefitted from the use of
radio tracking and/or satellite telemetry. Applying such techniques to Brolgas and using them in conjunction with a comprehensive habitat sampling program of foraging and roost sites would address the above issues and provide greater insight into habitat use and spatial requirements during the entire annual cycle.

The importance of different food items was inferred from the time spent feeding within different patch habitat types. Differential handling time of food items (e.g. a grasshopper vs. a cereal seed) may also influence foraging times within habitat types and may lead to potentially spurious conclusions as to the importance of different food items to Brolga diet. The relative importance of different food items could be better elucidated by the use of non-destructive stable isotope analysis of feather tissues (Hobson and Clark 1992; Phillips et al 2005).
Conclusion

The present study sought to obtain baseline information on time budgets, habitat use and spatial requirements of Brolgas at south-west Victorian flocking sites and to identify factors which may be limiting the population during the flocking season. The findings indicate that habitat use and site selection is dynamic both spatially and temporally and that flocking Brolgas have a requirement for a complex of certain habitat features distributed in close proximity to each other. It is proposed that important habitat features include: i) at least one shallow nocturnal roost wetland (fresh or saline) which is permanent and protected from human disturbance; ii) a source of fresh drinking water (wetland or otherwise); iii) at least one shallow secondary roost wetland for staging comfort behaviour; iv) access to high net energy yield food items (from crops, wetlands or grasslands), and v) a diverse range of animal foods to provide protein and calcium (from pasture, wetlands or grasslands).

Management of Brolga flocking habitat in south-west Victoria should therefore focus on improving the availability and quality of the essential habitat features listed above. It is likely that flocking Brolgas are limited mainly by the availability of wetland roosting and drinking sites. As Brolgas appear to be exhibiting preferential flocking site selection, the potential risks associated with between-site migrations within the flocking season should be determined and addressed. Future research should focus on determining the role of temporal and spatial heterogeneity in Brolga habitats by use of radio tracking and/or satellite telemetry, comprehensive habitat sampling and dietary analysis through stable isotope studies.
References


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