University of Technology, Sydney

Faculty of Science

Department of Environmental Sciences

Population ecology of the Australian White Ibis, *Threskiornis molucca*, in the urban environment.

Andrew Charles Michael Smith

BSc (University of Technology, Sydney)

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Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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PhD Thesis

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Abstract

The Australian White Ibis (*Threskiornis molucca*) has dramatically increased in many coastal urban environments, while it has decreased in large areas of its traditional environment range in inland Australia since the 1970s. Ibis are often viewed as pests in urban environments due to the social, economical and environmental problems they can cause. Current, management of ibis in the urban environment predominately focuses on restricting their breeding success, in order to reduce abundances. Management can be costly, labour intensive and limited in its success, due to a lack of detailed knowledge of the ecology of urban ibis. The focus of this thesis is to explore various ecological parameters of urban ibis to increase the effectiveness of their management. Three major breeding/roosting colonies of ibis were monitored weekly for a whole year (2005 to 2006). In addition, five major landfills for domestic waste were investigated for avian abundances and diversity. My main aims were to provide details on the reproductive biology, population dynamics, local and regional movements and the use of landfills by ibis. In comparison to non-urban ibis, urban ibis have a longer breeding period, smaller mean egg volumes and clutch sizes, but a larger range of clutch sizes. They also have a lower hatching success, but higher reproductive success and a higher mean number of fledglings per clutch. Each roosting/breeding and landfill site differed in their reproductive success and/or population dynamics. Ibis used multiple sites for breeding and feeding and were capable of moving over vast distances after they had fledged. The ability of ibis to obtain food from anthropogenic sources appears to be one of the key factors in the urban environment that allows them to survive and breed there. Management plans need to consider this and their decline in their traditional environments to be effective, without harming the overall survival of this native species.

Student declaration

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Andrew Charles Michael Smith

June 2009

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Publications (originating from this study)

Papers:

- Smith, A. C. M., and Munro, U. (2008). Cannibalism in the Australian Pelican (*Pelecanus conspicillatus*) and Australian White Ibis (*Threskiornis molucca*). *Waterbirds* **31**, 632-635.
- Smith, A. C. M., and Munro, U. (2010). Seasonal population dynamics of the Australian White Ibis (*Threskiornis molucca*) in urban environments. *Emu* (in press)

Conferences:

- Smith, A.C.M., Corben, D.T., Ross, G., and Munro, U. (2006). The Australia White Ibis – our vulnerable urban pest? *Biodiversity Extinction Crisis Conference,* Sydney, March.
- Smith, A.C.M., Ross, G., and Munro, U. (2007). Breeding success, movements and management of the Australian White Ibis, *Threskiornis molucca*. *Australasian Ornithological Conference,* Perth. December.
- Smith, A.C.M., and Munro, U. (2009). The Australian White Ibis: ecology of an urban waterbird. *Birds and Water – Birds Australia Southern NSW & ACT Seminar,* Sydney, April (by invitation).
- Smith, A.C.M., and Munro, U. (2009). Population ecology of the Australian White Ibis, *Threskiornis molucca,* in an urban environment. *10th International Congress of Ecology*, Brisbane, August, and *Australasian Ornithological Conference,* Armidale, December.
- Smith, A.C.M., and Munro, U. (2009). Food for thought: urban landfills, not a wasteland for some of Australia's birds. *Australasian Ornithological Conference,* Armidale, December.

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Thesis structure

This thesis includes seven chapters. The first chapter provides background information on the ecology of the Australian White Ibis (*Threskiornis molucca*), identifies gaps in knowledge, and states the significance and aims of this thesis. The next five chapters (data chapters) have been prepared as manuscripts for submission to peer-reviewed journals. Formatting may vary between these chapters and depend on the relevant editorial and other requirements of the journal the manuscript will be submitted to. This means that there exists some overlap and repetition in particular in the methodology and background information of ibis in these chapters. The final chapter summarises the main conclusions from each data chapter, details major findings and their implications, and suggests directions for further research. References are provided for every chapter.

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Chapter 1.

General Introduction.

Urban wildlife

Urbanisation has had a profound influence on the abundance and distribution of avian fauna and global biodiversity in general (Beissinger and Osborne 1982; Blair 2001; Chace and Walsh 2006). In Australia, urbanisation typically results in pollution of air, water and land; a loss of native vegetation and its structure; degradation in local water quality and flooding regimes; and increases of exotic species (Lindenmayer 2007). In 2004, three quarters of the Australian population lived within urban environments (ABS 2006).

Within the highly modified and dynamic landscape of the urban environment there are some species that have benefited from these modifications of their natural habitat (Lunney *et al.* 2007). However, many species have declined or become locally extinct as a result of urbanisation (Lunney *et al.* 2007). In Australia, native species that have adapted and seem to benefit from the urban environment include: the Australian White Ibis (*Threskiornis molucca*) (Martin *et al.* 2007); Grey-headed Flying Fox (*Pteropus poliocephalus*) (Eby and Lunney 2002); Rainbow Lorikeet (*Trichoglossus haematodus*) (Smith and Lill 2008); and Silver Gull (*Larus novaehollandiae*) (Smith and Carlile 1992). These animals occur in high densities in the urban environment, where they cause economic, environmental and social problems (Corben 2003), and are therefore considered a pest (Martin *et al.* 2007). Management of these overabundant native species is complicated, since their long-term survival needs to be considered in management plans (see Corben and Munro 2008).

Another major problem associated with urbanisation is the production of large amounts of domestic waste, which in Australia is mostly deposited in landfills (ABS 2006). High concentrations of waste often attract a wide variety of foraging animals (Adams *et al.* 2006). This can result in some species (e.g. gulls) becoming locally overabundant (Smith and Carlile 1992). Landfills can also help to support endangered species, such as the White Stork

(*Ciconia ciconia*) in Europe (Blanco and Marchamalo 1999), which complicates the management of landfills, and its wildlife. Another species that currently benefits from landfills is the Australian White Ibis (*Threskiornis molucca*) (Ecosure 2009). This species occurs in large numbers in urban environments, where it feeds from landfills, but has undergone massive population declines in its traditional distribution range (Porter *et al.* 2006). The Australian White Ibis is the focus of this thesis.

The Australian White Ibis

The Australian White Ibis (*Threskiornis molucca*) (previously known as the Sacred Ibis, (*T. aethiopica*) (Lowe and Richards 1991)), is a stork-sized bird that is easily recognised by its white plumage, bare black head, and long, downward curving bill (Slater 1987). Immature and adult birds differ in plumage and other morphological features (see Fig. 1). The Australian White Ibis is a native bird to Australia and the southern parts of Papua New Guinea (Marchant and Higgins 1990). The natural habitats are terrestrial wetlands, grasslands and intertidal mudflats (Gosper 1981; Marchant and Higgins 1990). Traditionally ibis occurred along inland river systems (e.g. Murray-Darling river system), swamps and lagoons (Carrick 1959; Crawford 1972), where they mostly feed on aquatic invertebrates as well as small fish, amphibians, reptiles and mammals (Carrick 1959; Morris 1973; Vestjens 1973; Cowling 1974). Ibis also feed in grasslands and irrigated agricultural areas (Ross 2004). Since the 1970's their range has expanded into urban (Ross 2004) and coastal environments of eastern (Blakers *et al*. 1984; Shaw 1999; Ecosure 2009) and western parts of Australia (Bekle 1982) (see Fig. 2). In urban areas they inhabit open space areas (e.g. parks, picnic grounds, zoos, landfills) (Marchant and Higgins 1990; Perry 2001; Murray 2005).

Fig. 1. Illustration of an immature (left) and adult Australia White Ibis (right) (Pizzey and Knight 1997). Immature and adult ibis can be distinguished through differences in plumage, size and colouration of bare parts (e.g. legs, head, under-wing).

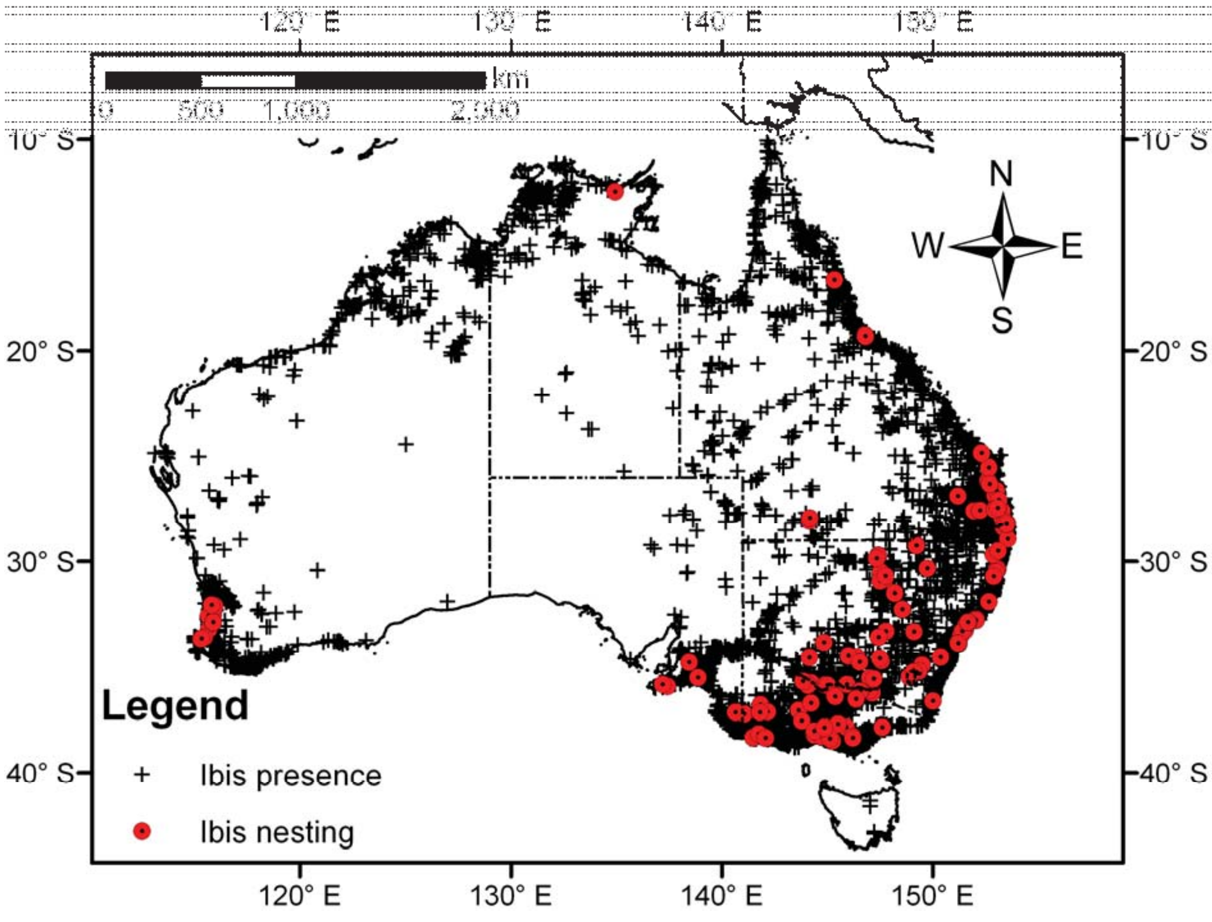

Fig. 2. Distribution and nesting records of the Australia White Ibis in Australia (New Atlas data, Birds Australia 2008).

Ibis are monogamous colonial breeders (Beilharz 1988) that predominantly nest close to water bodies, often with other species (Cowling and Lowe 1981; Lowe 1984; Marchant and Higgins 1990). Breeding is influenced by the presence and abundance of water, and flooding can stimulate breeding (Carrick 1962; Kingsford and Johnson 1998), while large drops in water levels can cause adults to abandon their nets (Holmsten 2003). Davis and Reid (1974) found that a lagoon reaching maximum volume triggered breeding, and in River Red Gum (*Eucalypus camaldulensis*) wetlands an inundation of nest trees is needed to initiate breeding (Briggs *et al.* 1997; Briggs and Thornton 1999). Kentish (1999) also reports that the number of nestlings in a breeding colony is positively correlated with the water levels during the preceding months when copulation occurs. Kingsford and Johnson (1998) obtained similar findings at the Macquarie Marshes, where water levels significantly influenced the number of breeding ibis. The introduction of dams and subsequent reduction of floodwaters resulted in significantly lower abundances of breeding ibis than those found there previously (up to 15,000 ibis in some years (Cowling and Lowe 1981; Blakers *et al*. 1984)). Today ibis are common in most large cities (e.g. Sydney, Melbourne, Brisbane, Gold Coast) (Meyer-Gleaves 2003; Ross 2004; Murray 2005; Ecosure 2009; unpubl. data). Their behavioural plasticity, flexibility in habitat selection, and tolerance to humans allows ibis to live in urban areas, and other areas, where ibis were once absent or uncommon (Bekle 1982; Ross 2004; Ecosure 2009).

Despite its proximity to humans and high abundance in cities, knowledge of the Australian White Ibis or any of the other 33 ibis species (Threskiornithinae) that occur around the world is generally poor (Hancock *et al.* 1992). Many species are endangered, critically endangered or have become locally extinct due to habitat destruction and hunting (Hancock *et al.* 1992; Pegoraro 1996). They include the Black (*Pseudibis papillosa*), Giant (*Thaumatibis gigantea*), Japanese Crested (*Nipponia nippon*), Madagascar Crested (*Lophotibis cristata*), Olive

(*Bostrychia olivacea*), Oriental (*Threskiornis melanocephalus*) and Waldrapp Ibis (*Geronticus eremita*) (Hancock *et al.* 1992; Devkar *et al.* 2006). Some of these species are very rare and/or live in areas that are inaccessible (e.g. Giant Ibis), rendering research efforts impossible. Research of common species, such as the Australian White Ibis, can aid conservationist in perfecting research techniques for rarer species.

Past and present habitat

In the 1960's ibis were rarely seen along the Australian east coast and no breeding occurred in this area (Morris 1983). They were held in Taronga Zoological Park, Sydney, and encouraged to breed in aviaries and later, during the 1970's as free ranging birds (Taronga Zoo 1990a). However, after they became aggressive towards people, park officials tried to remove them from the park (Taronga Zoo 1990b). Breeding of wild ibis began in Sydney in the 1980's, when wild birds were regularly found at Centennial Park, The Royal Botanic Gardens (Lindsey 1986) and Hyde Park (Lindsey 1985). From then onwards breeding in Sydney and other urban areas along the eastern coastline has increased continuously resulting in large breeding and roosting colonies today (Ross 2004). In Sydney they are common at Centennial Park, Hyde Park, The Royal Botanic Gardens, Lake Gillawarna (Bankstown), Cabramatta Flying Fox Reserve (Warwick Farm) and several landfills (e.g. Bellrose, Eastern Creek and Lucas Heights waste management plants) (Corben 2003; DEC 2005; D. Mulquin pers. comm.; J. White, Waste Service Management NSW, pers. comm.).

There are several hypotheses for the coastward range expansion of ibis (McGill 1966; Ross 2004).

1) The seven breeding pairs released at Taronga Zoo in the 1970's gave rise to the urban coastal populations (DEC 2005).

2) Habitat degradation (low water levels) through inappropriate irrigation practices has made it impossible for ibis to remain in their traditional breeding areas, forcing them coastward (Kingsford and Johnson 1998).
3) Inland droughts have forced ibis into wetter coastal areas for breeding (DEC 2005).

It is not certain which factor has caused the coastward movement of ibis. Theoretically any of the above factors or a combination of them could have contributed to their range expansion. What is known is that once ibis had arrived in the highly populated coastal areas, they soon learned to exploit anthropogenic food sources and commenced breeding (Ross 2004; DEC 2005; Ecosure 2009).

Status

Most urban residents, councils and environmental management agencies regard the ibis as a pest (DEC 2005; Ecosure 2009), because they:

- destroy habitats and reduce biodiversity (Kentish 1994);
- may transmit diseases to humans and livestock (Epstein *et al.* 2006);
- are a risk to air traffic safety (ATSB 2003; Corben 2003); and
- have a low aesthetic appeal (they are noisy, smelly and aggressive), and are a nuisance to the general public (Martin *et al.* 2007).

It is not surprising that environmental managers are concerned about overabundant ibis. Habitat and biodiversity management in areas with high ibis numbers is very costly and labour intensive (BCC 2004; DEC 2005). Interference with air traffic risks human lives and can result in costly damage to the aircraft. For example, in 1995, an ibis was ingested into an engine of a Qantas Airbus at the Gold Coast, resulting in damages worth AUS $8 million (Ecosure 2009). The Air Traffic Safety Bureau (2003) rates the ibis as the second most dangerous bird to air traffic, because it is large, moves in flocks and tends to occur near airports. Corben (2003) reported large flocks flying across the runways of Sydney Airport, making them a considerable risk to approaching and departing aircraft.

Several studies have identified ibis as seropositive for Avian Influenza, Newcastle disease, and *Salmonella, Giardia* and *Cryptosporidium* ssp (Epstein 2001; Legoe 2003; Epstein *et al.* 2006; Stark *et al.* 2008). Since landfills are a source of infection of *Salmonella* for Silver Gulls (Tizard 2004), it is likely that ibis also become infected when feeding on landfills and other anthropogenic waste (Epstein *et al.* 2006). Thus, ibis may be a vector for disease transmission, causing a potential risk for humans, livestock (poultry) and wildlife. However, to date there is no documented case where a human or any other animal has been infected with a disease from ibis (Epstein *et al.* 2006).

Management

Due to persistent complaints about ibis abundance and the negative impacts associated with these birds (DEC 2005), councils and other organisations have been under considerable pressure to reduce their numbers (DEC 2005). As there is very little known about the basic biology of ibis and management impacts are not monitored, current management practices are not guided by scientific knowledge and are mostly based on trial and error. Methods to reduce the urban populations (DEC 2005; Martin *et al.* 2007; Ecosure 2009) include:

- community education (e.g. signage to reduce feeding);
- removal and destruction of nests, eggs and chicks;
- culling (shooting) of adult birds;
- deterrence through noise, light, chemicals, raptors and other trained animals (dogs); and
- habitat/vegetation modification.

Many organisations have requested or obtained from the National Parks and Wildlife Service NSW (Department of Environment and Climate Change (DECC)) a licence to cull a predetermined quota of fledged ibis at Centennial Park, The Royal Botanic Gardens, Cabramatta Flying Fox Reserve (Fairfield Council) and Lake Gillawarna (Bankstown Council). Despite no opposition from the public, shooting is not a preferred option, because it eliminates only a small number of birds and poses a risk to public safety. The preferred method is nest and egg destruction, since it affects a higher number of birds and the task can be completed with little threat to human safety (BCC 2004).

The major aim of managers of urban ibis populations is to reduce their abundance by suppressing their breeding success, which is considered to be too high (Martin *et al.* 2007). However, since there is no scientific assessment of current management practices and their impact(s), it is not known whether these practices lead to an overall reduction in ibis numbers. At present, management practices appear to have little effect on the sizes of ibis colonies (pers. obs.). Despite massive nest/egg destruction programs (e.g., 4000 eggs (approximately 60% of total number of eggs) were destroyed in Centennial Park, Sydney, in 2002), most colonies have recovered quickly, with some even increasing in size. Several studies on other urban pest birds (e.g. Silver Gull and Mute Swan (*Cygnus olor*)) have shown that egg/clutch reduction alone is ineffective (Smith and Carlile 1993; Watola *et al.* 2003). In many animals, high density populations result in higher mortality rates than usual, particularly during breeding, while lower density populations can increase survival rates (e.g. Begon *et al*. 1986). Therefore it is possible that the current destruction rates favour the survival of the remaining eggs and young, resulting in no apparent change or even an increase in total population size.

There are also indications that since 2003, nesting colonies are increasing in number and are spreading over a large geographical area, while some of the older colonies are decreasing in size (G. Ross, NPWS, pers. comm.). It appears possible that some of the larger colonies have produced splinter populations, which have spread into new areas previously not occupied by ibis (e.g. Sydney's Darling Harbour, Cabramatta Flying Fox Reserve). Ibis have also started to nest in places (e.g. palm trees along roads) away from waterbodies, along which ibis traditionally nest (DEC 2005). This has never been reported previously. At present it is unknown whether this is a result of the current management practices or developed naturally. In any case the establishment of new colonies and the spread of ibis into new areas are of considerable concern, because it spreads the problems associated with ibis over a wider area and will make population monitoring and management more difficult.

It appears obvious that until we obtain more knowledge on ibis in urban environments, we will not be able to manage ibis effectively and predict management outcomes. Without proper management protocols we will also continue to waste valuable resources (staff time, money) on ineffective management practices, which could even worsen the problem by spreading and splintering ibis colonies. In order to improve management we urgently need baseline knowledge on reproduction, habitat requirements and abundances of urban ibis.

Reproductive Biology

Kingsford and Norman (2002) reviewed research on the ecology of Australian waterbirds and concluded that, relative to other Australian waterbirds, ecological information available for the Australian While Ibis is 'good'. Despite this, literature on the reproductive biology of the Australian White Ibis is sparse and most of our knowledge is based on only two publications (Lowe 1984; Beilharz 1988). These two studies focus on ibis in rural to semi-rural areas. In recent years some progress has been made in understanding the reproductive biology of urban ibis (BCC 2004; Corben and Munro 2006; Murray and Shaw 2006; Thomas 2007). However, while these studies have definitely contributed to our knowledge base of ibis, they suffer from the fact that they are based on small data sets (i.e. short observations with small sample sizes). Thus they cannot identify reproductive outputs of ibis and whether changes in the reproductive success between ibis breeding in urban and non-urban environments have taken place. Studies on other species suggest considerable differences in reproductive parameters between urban and non-urban populations (Schmidt 1986).

Studies of rural to semi-rural ibis (Beilharz 1988) reported average clutch sizes (eggs per nest) of 2.69 eggs ± 0.62 s.d. (n = 1004), with 70% of all nests containing three eggs. Lowe (1984), in another study of non-urban areas, reported similar mean clutch sizes between 2.52 and 3.21 eggs, with three egg clutches being the most common (85% of all nests). Lowe (1984) also found geographical variations in the breeding success of ibis. Mean fledging success ranged from zero to 1.29 fledglings per nest. Complete nesting failure of the whole colony occurred during three out of six breeding seasons at inland sites, whereas all sites near the coast continually produced at least some young. Highest fledging success was reported for Healesville's Wildlife Park (near Melbourne, Victoria), where 48% of all nests fledged more than one young; success rates at other sites ranged from 5% to 22%. Lowe attributed the high fledging success at Healesville to the high availability of protein-rich food, which the ibis stole from the park's animals. Lowe (1984) found that the food supply significantly influenced the reproductive success of ibis, but had no influence on other parameters such as clutch size. Clutch sizes of three eggs dominated, independent of season or geographical region.

Beilharz's (1988) study of one site at Healesville (Victoria) over four breeding seasons from 1983 to 1987 showed lower breeding successes (averaging 0.85 fledgling per nest out of 2025 breeding attempts over four years) than Lowe's (1984) studies. Fewer than 7% of nests fledged more than 2 chicks. 51% of nests failed (76.6% failed before hatching). Mortality rates after fledging were consistent until the fifth week. The results of these two studies suggest large variations of breeding success between seasons and sites.

Studies of ibis breeding in the urban environment have produced various outcomes. The first known study of ibis breeding in urban areas was conducted by Bankstown City Council (BCC) (2004) in the Bankstown area (western Sydney). This study found that fledging success was very low (approximately 30% of eggs laid fledged). The mean clutch size of 2.4 eggs was lower than that reported by Lowe (1984) (2.52 to 3.21 eggs per nest) and Beilharz (1988) (2.69 eggs per nest). The small clutch sizes in the urban environment may indicate that ibis reproduce less successfully than in rural and semi-rural environments. However, these results are based on a very small data set from one site and nests that were subject to a flood event (BCC 2004), so may not represent breeding success in the urban environment accurately.

In 2006 two studies (Corben and Munro 2006; Murray and Shaw 2006) were published on the breeding biology of the Australia White Ibis in an urban environment. Both papers are limited by the fact that they were based on small sample sizes. Corben and Munro (2006) reported a reproductive success of 100% (every egg laid produced a fledgling), which is remarkably high. The other study by Murray and Shaw (2006) was based on 95 nests. Their findings are similar to those of BBC (2004) in terms of average clutch size (2.46 eggs ± 0.71 s.d.) and reproductive success of 28.9%. These findings suggest that the reproductive success of ibis breeding in the urban environment may not be significantly higher than in their traditional environment. Given the extent and magnitude of the current drought in their traditional breeding area (Fig. 3), today's breeding success is probably lower than that in the past. It is possible that ibis breeding in the urban environment contribute to the species' survival (Corben and Munro 2008). Thus, the urban environment may constitute an environmental refuge, which ibis have been forced into since their traditional areas have become unsuitable. Detailed studies are needed that include both urban and non-urban colonies and extend over the whole breeding period to understand whether their current breeding levels are sufficient to sustain the species.

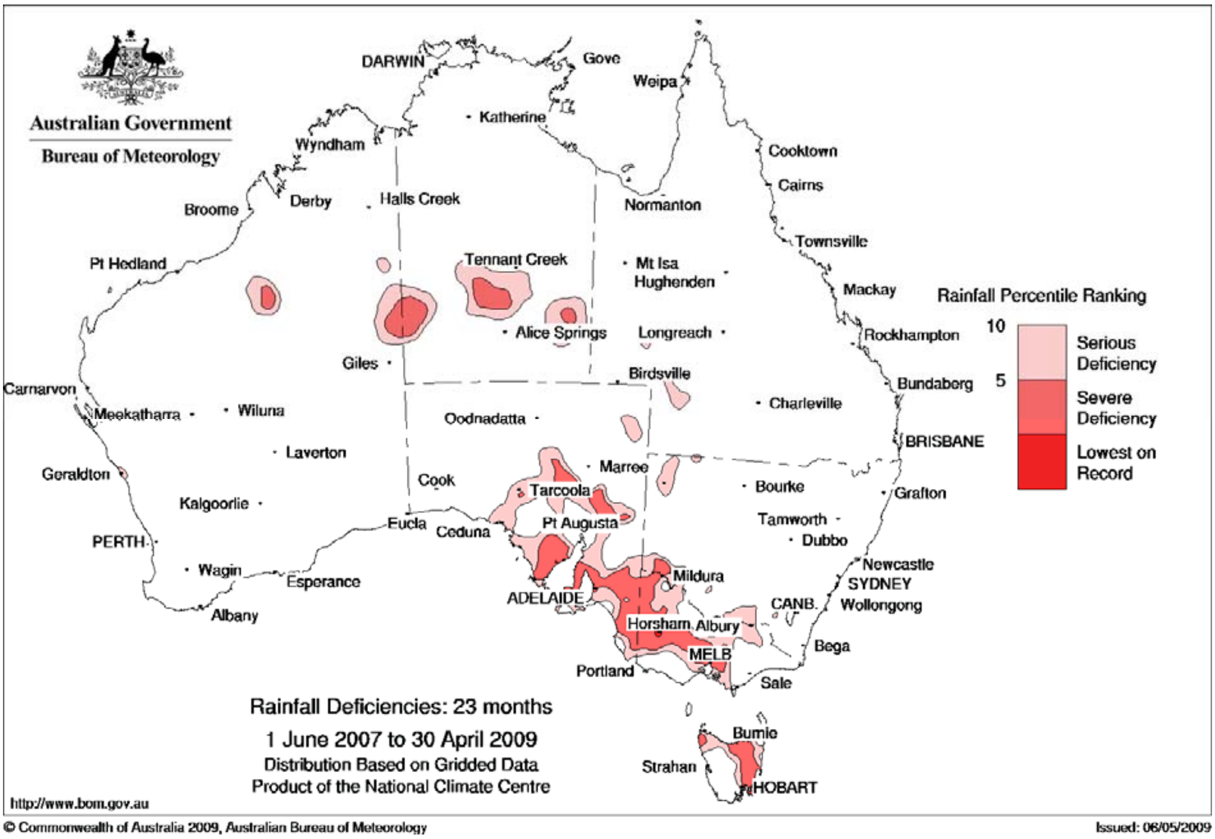

Fig 3. Map of long-term rainfall deficiencies over south-eastern Australia (ABS 2009).

Since ibis are a native species and protected under both the *New South Wales National Parks and Wildlife Act* 1974 and *Nature Conservation Act* 1992, an assurance is needed that their reproductive success rates remain high enough to sustain the species. Since breeding of ibis at their traditional inland breeding sites is currently declining dramatically (Porter *et al.* 2006), urban ibis might be the only ibis left that reproduce successfully and in sufficient numbers to ensure the survival of the species. Research on the breeding success of urban ibis is urgently needed to manage the species appropriately, so that their survival is not endangered.

Population Dynamics and Movements

Knowledge on the abundance and movements of both coastal and urban ibis is poor. Porter *et al.* (2006) performed aerial surveys of waterbirds in inland Victoria, New South Wales and southern Queensland annually from 1983 to 2005 (Fig. 4). Ten survey bands (30 km wide) were centered on each 2º of latitude from 38º30'S to 20º30'S. The results of two counters were averaged from all wetlands larger than one hectare within each band. This long-term study provided an insight into the abundances and fluctuations of the ibis population from inland NSW. Abundances fluctuated considerably, which could be at least partly due to the nomadic lifestyle of ibis in semi-arid regions (Fig. 4). Ibis tend to congregate wherever rain has produced flooding and commence breeding (Carrick 1962). Ibis could have easily responded to rain events causing movements in and out of Queensland and Victoria resulting in large annual population size variations in NSW. In order to obtain an accurate measure of ibis abundances, surveys are needed on a continental scale. Despite the lack of these, the dominant trend in abundances is an exponential decline in the bird's traditional range of eastern Australia (Fig. 4).

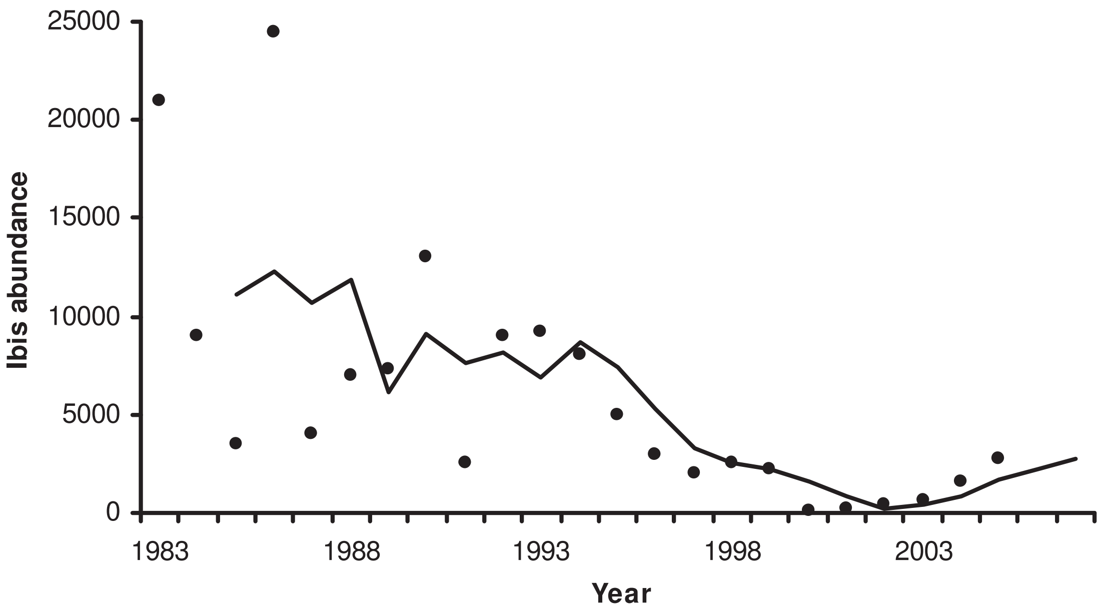

Fig. 4. Population abundances of the Australia White Ibis in south eastern Australia between 1983 and 2005 (modified from Porter *et al.* 2006). The solid line represents a three-year moving average.

Although the exact number of ibis in coastal areas and urban environments of eastern Australia is unknown, our knowledge on their abundance has increased lately. Their numbers were found to fluctuate dramatically, with low numbers during the non-breeding season (February/March to June) and high numbers during the breeding season (July to January) (Corben 2003; G. Ross, NPWS, pers. comm.). Corben's (2003) study on the Centennial Park population in Sydney suggests that approximately 20% are resident birds (present during the whole year), while 80% of the population (approximately 1200 individuals) moves into Centennial Park for the breeding season. Corben and Munro (2008) have proposed that a migratory subpopulation of ibis exists in Sydney and possibly other urban environments, which enters the city for breeding.

To test this, Thomas (2007) performed community surveys of ibis abundances that included all of New South Wales and approximately a third of Queensland (southern part only). Two surveys were conducted, one in the non-breeding season (March to April) and one in the breeding season (June to July) of 2007. The data showed a clear increase in almost all coastal areas (east of the Great Dividing Range) and a decrease in the interior areas (west of the Great Dividing Range) during the breeding season in comparison to the non-breeding season. This study gave the first clear evidence that ibis are moving from inland Australia to the coast during the breeding season, most likely for breeding purposes. However, this study is limited by a number of factors. It only included one year of data and did not include Victoria. From atlas data (Fig. 2), we know that Victoria not only has a high abundance and wide distribution of ibis, but also a high proportion of breeding colonies in Australia (Cowling and Lowe 1981). Thus a high proportion of ibis were probably excluded in this study. This study also did not include the effect that the number of juveniles would have on population abundances. Since atlas (1998-2008) data suggest that most ibis are breeding on the coast instead of inland

Australia (Fig. 2.), it is possible that the abundance changes Thomas (2007) observed were due to increased numbers of fledglings in the coastal area during the breeding period.

Surveys by Porter *et al*. (2006) during the breeding period (October) show a decrease in ibis abundances in inland areas, while abundances have increased in the urban environment (Thomas 2007). This also suggests that ibis are leaving their traditional breeding ranges in NSW to breed in coastal urban environments. However, aerial surveys during the non-breeding period are needed to confirm this hypothesis. While Corben's (2003) study on the abundance of urban ibis is of considerable interest, his study is limited by the fact that it is restricted to the pre-breeding and early breeding period, and only focuses on one site. In order to assess whether his hypothesis is valid, a more detailed study on urban ibis populations is needed that also accounts for the number of juveniles. In order to do so, a long-term study (of at least one year) of ibis abundances on a larger scale is needed, which does not focus on a single colony, but includes all major urban colonies.

Carrick (1962) studied large scale movements of ibis in Australia. Of the 1397 fledglings banded only 22 birds were recovered (1.5%), illustrating the difficulties associated with band recoveries for this species. The longest journey of an ibis (almost 3200 km) stretched from Kerang, Victoria, to Papua New Guinea (Purchase 1976). Lowe's (1984) study of fledging dispersal over three years found that many ibis stayed within the vicinity (200 km) of the hatching site. Both he and Carrick (1962) found strong movements directed towards the east coast. However, no seasonal movements have been identified to date (Blakers *et al.* 1984; Barrett *et al*. 2003). It is believed that once chicks have fledged, they drift towards the coast. Once they find the coast, they tend to move north, following the coast line with some travelling as far as Papua New Guinea (Carrick 1962; Purchase 1976). Flocks of 20 - 5000 birds have been observed crossing Torres Strait (Blakers *et al.* 1984), which also suggests that there may be a north south migration along eastern Australia. The duration that ibis stay in the north is not known. Since the ibis in Sydney and other coastal cities appear to consist of mainly mature adults (and their offspring after the breeding period), juveniles may move north after the breeding season, and similar to European White Storks (Berthold 2001), only return when sexually mature and ready to breed.

The National Parks and Wildlife Service (NPWS) of NSW has in recent years conducted an ibis banding program in Sydney with a focus on juvenile dispersal both locally and over long distances. Of the 26 banded birds that were recovered, only two were discovered outside the wider Sydney region. One bird was recovered in Townsville and on the Gold Coast, Queensland (banding records of G. Ross, NPWS), supporting the hypothesis of northward movements of young ibis. Current banding rates of adult ibis are much lower than those of juvenile ibis due to the difficulties in catching adults; therefore their local and large scale movements remain unknown. Some studies on adult ibis indicate that they have small home ranges (Perry 2001) and usually do not venture above 3 km from their roosting quarters, but can move up to 25 km in day (Murray 2005). However, at Phillip Island, Victoria, ibis flew up to 15 km each day from the breeding colonies to their feeding sites (Blakers *et al.* 1984). Although these studies suffer from small sample sizes, they do indicate that some ibis are sedentary, and that breeding and feeding sites are linked.

Juvenile ibis are known to travel over long distances (over 3000 km) (Carrick 1962; Purchase 1976; Lowe 1984)). There is also evidence for long distance movements of adult ibis, during dry conditions and when wetland water levels fluctuate greatly (Carrick 1962; Marchant and Higgins 1990), which means that ibis are capable of travelling from inland to coastal areas of Australia (Ross 2004). Peaks in ibis populations have also been observed in Sydney during non-drought years (J. Cartmill, records of Centennial Park and Moore Park Trust, Sydney), so may not be directly related to inland droughts, but may reflect regular annual movements. This would imply that the ibis population of Centennial Park and possibly other coastal cities are comprised of a permanent sedentary subpopulation and a mobile subpopulation present only during the breeding season (Corben and Munro 2008). Seasonal long-distance movements between breeding and non-breeding areas across Australia also occur for the closely related Straw-necked Ibis (*T. spinicollis*) (McKilligan 1975; Lowe 1984; Griffioen and Clarke 2002). This species is a partial migrant, with a mobile subpopulation moving between breeding and non-breeding areas, and a sedentary subpopulation remaining in the breeding areas (McKilligan 1975; Marchant and Higgins 1990). It is possible that favourable environmental conditions in coastal cities are sustaining sedentary ibis populations and encouraging inlands birds to move into these cities annually (Corben 2003).

As yet, we know too little about the movements and reproductive biology of ibis to conclude with certainty from where the ibis in Australia's coastal urbanized areas originate, and whether movements are initiated purely by unfavourable environmental conditions in traditional roosting, feeding and breeding areas, or are based on regular migrations of proportions of the population. Regardless of this, the movements of ibis into urban areas have considerable implications on the management of this species. Management of Sydney's and other urban ibis populations regularly involves egg and nest destruction and culling to control growth (Ecosure 2009). If long-distance movements of ibis commonly occur, then these management practices may actually be reducing regional populations rather than local urban populations. Therefore, urban management needs to be cautious and aware of the potential impact on the wider ibis population until local and long-distance movement patterns are clarified.

The decline of ibis in western NSW correlates with the increases of ibis in Sydney and on the Gold Coast. This supports the hypothesis that the urban ibis populations do not originate from the introduced individuals by Taronga Zoological Park (as discussed above), but rather immigrated from western NSW. It appears that significant numbers of ibis have left and are still leaving their natural range in preference of an urban environment. Current ibis management strategies need to consider the implications of their actions for ibis populations from inland Australia, as they may not deal with separate ibis populations. Thus to manage the existing ibis populations' sustainability, an understanding of their reproductive biology, population dynamics, movements and use of landfills is required to formulate management plans. There also need to be protocols in place that incorporate monitoring of the impacts of management. The continuing lack of knowledge of this species may otherwise lead to inappropriate management strategies and potentially an overall decline of the species.

Aims

The high abundance of the Australia White Ibis in urban areas clearly poses a serious environmental problem, which requires immediate attention in order to halt further environmental degradation, risk to aircraft traffic and human health (Corben and Munro 2008). However, the Australian White Ibis is a native species and therefore protected under both the *Nature Conservation Act* 1992 and *New South Wales National Parks and Wildlife Act* 1974. Thus, when developing management plans for ibis, their movements and apparent decline in inland NSW needs to be taken into account, so that the species is not harmed on a regional scale. Until the broad scale movements of ibis are clarified, management programs aiming to reduce breeding success must be responsible and ensure the breeding success of ibis remains at a sustainable level. Management could also spread and/or fragment populations (Clergeau 2005), which could render future management difficult. Detailed knowledge of biological parameters is essential for the development and implementation of management strategies (Corben 2003), such as habitat and resource requirements, movements, abundances and breeding success. This means a regional or larger scale approach to management would be the most effective way to manage the sustainability of this species.

The following study will focus on the reproductive biology and the population dynamics of ibis in the urban environment. The purpose of this study is to provide relevant information with a strong scientific background for the decision-makers of ibis management plans. This information is currently lacking and is of particular importance for the understanding of management strategies for the species. The specific aims of this study are to describe the:

- breeding biology of the Australian White Ibis in urban environments (Chapter 2 and 3);
- population dynamics of the Australian White Ibis in urban environments (Chapter 4);
- local and regional movements of the Australian White Ibis (Chapter 5); and
- use of landfills by ibis and other birds (Chapter 6).

The research has been performed at three major colonies in the Sydney area located at Centennial Park, Lake Gillawarna (Bankstown) and Woy Woy (Central Coast). Sites will be compared to each other and to the few mainly rural and semi-rural sites investigated (Carrick 1962; Lowe 1984; Beilharz 1988; Kentish 1999; Corben and Munro 2006; Murray 2005). Also areas of future research will be identified. The waste management sites included in this study are the Belrose, Eastern Creek, Kincumber, Lucas Heights and Woy Woy landfills.

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Chapter 2.

Breeding biology of the Australian White Ibis (*Threskiornis molucca*) in the urban environment.

Abstract. The Australian White Ibis (*Threskiornis molucca*) has increased dramatically in the urban environment since the 1970's. Information on the reproductive biology of urban ibis, which is essential for the development of management plans, is rare. Here we studied the reproduction of Australian White Ibis at three urban sites in the wider Sydney area over an entire breeding period (2005-2006). This study provides the most comprehensive analysis of the breeding biology of urban ibis today, and also describes the growth of chicks. In comparison to non-urban ibis, urban ibis had a longer breeding period (every month of the year, except April, with highest breeding activity between June and February), smaller egg volumes and clutch sizes, but a larger range in clutch sizes. They also had lower hatching success (% eggs that hatched), but a higher mean number of fledglings per clutch and a higher reproductive success (% eggs that hatched and fledged).

Introduction

The Australian White Ibis (*Threskiornis molucca*) and its close relative the Sacred Ibis (*T. aethiopicus*) are currently causing considerable problems for environmental managers (Ross 2004; Clergeau *et al.* 2006). While the Sacred Ibis, originally a native to Egypt, where it is now extinct (Hancock *et al.* 1992), has invaded South Africa (Anderson 1997; Kopij 1999), several parts of Europe (Clergeau *et al.* 2006), and the USA (Herring and Gawlik 2007), the Australian White Ibis has since the 1970's expanded its breeding range into the eastern coastal and south-western regions of Australia to include urban centres (Bekle 1982; Ross 2004; Ecosure 2009). At the same time it has dramatically declined in its traditional range in the inland parts of south-eastern Australia (Porter *et al.* 2006). Today the Australian White Ibis forms large roosting and breeding colonies in many coastal urban environments, where it is believed to damage terrestrial and aquatic environments (Ross 2004); carry diseases dangerous to humans and animals (Epstein *et al*. 2007); be a major hazard to aircraft safety when near airports (ATSB 2002; Corben 2003); and be a general nuisance in open space areas, scavenging and dispersing litter, and harassing and stealing food from people (Ross

2004; DEC 2005; Murray and Shaw 2006; Martin *et al*. 2007; Corben and Munro 2008; Ecosure 2009).

Many government and non-government agencies are currently trying to manage urban ibis populations predominantly by culling adults and/or destroying nests and eggs (Ross 2004; DEC 2005; Murray and Shaw 2006; Martin *et al*. 2007; Ecosure 2009). Management has focused on limiting their breeding success in order to restrict recruitment to the urban population. However, this is cost and labour intensive and often difficult (Ross 2004; DEC 2005; Murray and Shaw 2006; Martin *et al*. 2007; Ecosure 2009), since very little is known about urban ibis and the effects of management on the sustainability of this species (Corben and Munro 2008). Since ibis have massively declined in their traditional range (Porter *et al.* 2006), urban colonies may be important for the species' survival (Corben and Munro 2008).

Since populations are influenced by breeding outcomes, prerequisite for their management is the understanding of their breeding biology and success (Gotelli 2001). As yet, very little is known about the Australian White Ibis' reproductive biology. Research on ibis from non-urban areas, before the population expansion, are limited to Lowe's (1984) thesis. While this study does not explain the current breeding success, it may serve as a reference to evaluate changes in the breeding biology of ibis since their establishment in the urban environment. In addition, some studies exist from urban environments (Kentish 1999; Corben and Munro 2006; Murray and Shaw 2006; Thomas 2007). However, these studies are of limited value, since they have focused on a small number of nests at a single site, and do not cover the whole breeding period.

The purpose of this research is to remedy this situation by including several colonies and study them over a whole year, so that better baselines for future management and its assessment are obtained. Since knowledge of ibis in general is poor, our work will also provide information on this family and may assist in managing the closely related Sacred Ibis, another invasive species (Clergeau *et al.* 2006), and the endangered Oriental White Ibis (*T. melanocephalus*) (Devkar *et al.* 2006).

Methods

Study animal

The Australian White Ibis (*T. molucca*) (hereon referred to as ibis) occurs in Australia, southern Papua New Guinea and a number of small islands in the Torres Strait (Purchase 1976; Draffan *et al.* 1983; Blakers *et al.* 1984; Marchant and Higgins 1990; Barrett *et al.* 2003). It is closely related to the Sacred Ibis (*T. aethiopicus*) of Africa, and was until recently regarded as this species (Lowe 1984; Lowe and Richards 1991). The Australian White Ibis traditionally nests/roosts near water bodies and on small islands within inland wetland systems (e.g. Murray-Darling river system (Carrick 1962)). Today it is very common in urban parks and landfills, which it uses as feeding sites (Ross 2004). Ibis are gregarious (Ross 2004), forming large colonies, some of which can contain up to 15,000 individuals (Carrick 1962; Cowling and Lowe 1981). Breeding periods traditionally vary depending on flooding and drought, which means that some sites are not used every year (Marchant and Higgins 1990). In general, ibis are monogamous, but can change partners between clutches and even mate with different partners, while incubating or rearing their own clutch with their partner (Beilharz 1988). Generally three eggs are laid in 48 hour intervals in a nest made from sticks, and are incubated for 20-23 days by both sexes (Lowe 1984; Beilharz 1988). After three weeks, chicks leave the nest, but depend on their parents for another three weeks (Lowe 1984; Beilharz 1988). Once ibis have fledged, they can travel large distances (Carrick 1962; Purchase 1976; see also chapter 5).

Study sites

The breeding biology of the Australian White Ibis from three urban colonies was studied in the wider Sydney area (New South Wales, Australia). The colonies were located at: (a) a sand island in the Brisbane Waters estuary at Woy Woy (WW) (32°30'S, 151°20'E) (~80 km NNE from Sydney's centre); (b) Lake Gillawarna (LG), Bankstown (33°32'S, 150°35'E), an artificial wetland in western Sydney; and (c) Centennial Park (CP) (33°32'S, 151°8'E), an urban park (360 ha) in eastern Sydney. All colonies were confined to small islands with the following sizes: 0.10-0.50 ha (depending on tidal levels) at WW, 0.45 and 0.03 ha at LG (two islands), and 0.04 ha at CP. These islands were surrounded by water throughout the entire breeding period. All nests were either on the ground or on vegetation of <2 m above the ground. All sites were close to (<20 km) landfills for domestic waste, which were regularly used by ibis for foraging and roosting (pers. obs.). The island at WW also contained a large breeding colony of ~500 Australian Pelicans (*Pelecanus conspicillatus*). Some of the islands at CP, where ibis were breeding, had a number of their nests disturbed by park authorities, so these islands were not included in any of the analyses.

Data collection

Nest and egg recordings

The ibis colonies of all three sites were visited once per week between 1 April 2005 and 1 April 2006. During each visit, new nests with one or more eggs were individually marked with numbered coloured cattle tags (Leader Product, Craigieburn, Australia). The eggs in each nest were also individually labelled with a xylole-free (non-toxic) felt pen (Artline - Garden Marker Black 780, Gold Coast, Australia). The nests' state (presence or absence) and content were monitored during subsequent visits. During these visits all newly laid eggs were labelled and recorded. It was also recorded, whether nests were reused for new clutches after the first clutch was raised or lost. To prevent mortality of the eggs and hatchlings from adverse weather and predation, the nests adults had left during the recording and labelling process were covered with cotton sheets or bags. Egg labelling appeared to cause little disturbance to the birds (but see Frederick and Collopy 1989), and they generally returned to their nest within 5-10 minute after the process and continued tending to their eggs/chicks.

The lengths and widths of the eggs were measured to the nearest 0.1 mm with vernier callipers (ZZW Precision Tool Supply, Shanghai, China) to determine egg volume. Also the weight of each egg was measured to the nearest 0.5 g using 100g Pesola scales (Rebmattli, Switzerland). Since egg numbers on our study island in CP were low in comparison to previous years (Corben and Munro 2006), egg sizes and weights were also measured on two inlands in CP that were the focus of an eradication program (Martin *et al*. 2007). These nests and eggs were excluded in the analysis of other reproductive parameters (see below).

We also excluded 114 of 751 nests at WW in the analysis as these nests had lost or gained eggs from neighbouring nests, which resulted in reduced or inflated clutch sizes (see chapter 3). Also eggs and hatchlings of roughly half of the colony at WW (n = ~50 nests) were not directly monitored between 3 Sep 2005 and 3 Jan 2006, since pelicans from adjacent nests frequently attacked unprotected ibis nestlings. However, the number of active nests was recorded with binoculars (10 x 40 magnification, Zeiss, Germany) from a distance.

<u>Growth rate</u>

Chicks that had hatched on the day of our visit were weighed with 100g Pesola scales (Rebmattli, Switzerland). As the chicks grew, Pesola scales with a wider range (e.g. 300g, 600g, 1000g and 2500g) (Rebmattli, Switzerland) were used. We also recorded the chicks' head-bill, bill, wing, tarsus and tail length with vernier callipers (ZZW Precision Tool Supply, Shanghai, China), a ruler (Australian Bird Study Association (ABSA), Victoria) and a tape measure (locally bought) on each visit until the chicks fledged (generally at approximately 21 days of age). During these visits young chicks were re-identified by their relative size to other chicks in the individually marked nests. This was possible because the eggs hatch asynchronously. Once the chicks were approximately 10 days old (age when chicks can leave their nest when disturbed) and their tarsus had reached a minimal length of 45mm, an individually numbered band from the Australian Bird and Bat Banding Scheme (ABBBS, Canberra) was applied to their right tarsus, to enable identification during subsequent visits (WW: 131 young banded, LG: 102 young banded). For some chicks (n = 150) the hatching date was unknown, and was estimated from their head-bill length as this morphological parameter (see Fig. 2b) varied least for the first 20 days in comparison to others (see Fig. 2a, c-f). To gain a surrogate for growth limits of ibis, 26 adult ibis were caught between 17 Jan and 24 Mar 2006 at CP and their body weight and other morphological parameters (see above) were measured. These birds were banded to prevent recapture and re-measuring the same birds.

Data analysis and statistics

The data from CP were included for calculating the breeding period, egg sizes and weights, and mean clutch sizes, but were excluded from all other analyses due to small sample sizes. Homogeneity of variance and distribution normality was determined by the Levene's and Kolmogorov-Smirnov tests, respectively. All statistical analyses were conducted using the SPSS software package (Version 14.0) and were assessed at the P = 0.05 significance level. WinCurveFit (Version 1.1.5, Kevin Raner Sofeware) was used to identify the best model for the growth rate of chicks.

<u>Breeding, incubation and fledging period</u>

We identified the breeding duration for each site from the first and last nest record with eggs and/or hatchlings. We also determined the incubation period of eggs, and once hatched, the time it took chicks to fledge at each site (WW and LG). The mean number of clutches per nest ± standard error (s.e.), and the range and mode (%) of clutch sizes were calculated for WW and LG and compared to each other with an independent-sample t-test (two-tailed).

Egg sizes and weights

From the egg lengths, widths and weights the means ± s.e. and ranges of each parameter were calculated for each site (WW, LG and CP). Egg volumes (*V*) were determined with the equation V = K x length x width^2, where the constant K = 0.507 (Hoyt 1979). The means of each parameter were compared between sites using a one-way ANOVA. To be able to compare our egg volumes to those from other studies on ibis, we calculated egg volumes (Hoyt 1979) from the egg lengths and widths stated in these publications (Lowe 1984; Murray and Shaw 2006; Thomas 2007).

Clutch sizes

The mean clutch sizes (number of eggs per clutch) ± s.e. and their ranges were calculated for each site (WW, LG and CP) and compared to each other with a one-way ANOVA. The overall frequency (%) of each clutch size (1-5 eggs) was also calculated for all sites, which revealed the most common (mode) clutch size for each site (WW and LG), except for CP, where samples sizes were too small.

Breeding success – hatchlings and fledglings

Firstly, the frequencies of clutches (%) that produced zero, one, two, three and four hatchlings(s) and fledgling(s) were calculated for both WW and LG. Then the mean ± s.e. and range of the number of (1) hatchlings and (2) fledglings produced per clutch, and (3) fledglings produced per nest were calculated for both WW and LG. The results of each of these calculations were compared to each other using an independent-sample t-test (two-tailed). Also, the hatching success (% eggs that hatched), fledging success (% hatchlings that fledged) and reproductive success (% eggs that hatched and fledged) were calculated from the total number of eggs, hatchlings and fledglings for both WW and LG.

Growth rate of hatchlings

The growth data of ibis chicks from WW and LG were combined, as they overlapped, to increase statistical power. Then the mean ± standard deviation (s.d) body weights and head-bill, bill, wing, tarsus and tail lengths were calculated for fresh hatchlings, 21-day old chicks (approximate age when clicks fledge (see Lowe 1984)) and adult ibis (> three years old (see Beilharz 1988)). We used the Quasi-Newton method for estimating the constants of the sigmoid-regressions (y=a((exp(b(x+c))-1)/(exp(b(x+c))+1))+d) to describe the increases in weight and other morphological parameters of chicks over time (days), as this model fitted the data best (highest R^2 values). For the mean adult weight and morphological parameters, we also calculated their 95% confidence intervals. All adult parameters had a normal distribution ($P > 0.05$; Kolmogorov-Smirnov tests), except head-bill and bill ($P > 0.05$), which had a bi-model distribution. These differences are indicators of the two sexes in ibis (Beilharz 1988), so males ($n = 15$) and females ($n = 11$) had their mean head-bill and bill lengths ± s.d. and 95% confident intervals calculated separately. We chose the gap in our data between 218 and 230 mm in head-bill length to differentiate between the sexes.

Results

Breeding, incubation and fledging period

Ibis bred between mid May 2005 and late March 2006 (10.5 months) at WW; early July 2005 and late January 2006 (7 months) at LG; and mid May and late December 2005 (7.5 months) at CP. The total number of nests and clutches over the whole study period differed between sites (see below). Some nests were re-used, thus held multiple clutches. We recorded 661 nests (with 887 clutches) at WW; 216 nests (with 337 clutches) at LG; and 10 nests (with 15 clutches) at CP (Fig. 1). WW had a significantly lower mean number of clutches per nest

(1.34 clutches ± 0.03 s.e.; range: 1-5; mode: 1 (73.5%)) than LG (1.56 ± 0.06 s.e.; range: 1-5; mode: 1 (60.6%)) ($t(875) = -3.614$, $P < 0.001$, t-test). The abundance of active nests varied throughout the 2005/2006 breeding season for all sites (Fig. 1). The number of nests at WW increased steadily from May to August, despite a severe storm during early June, which destroyed approximately half of all nests. The number of active nests at LG did not rise until July (two months after WW). The number of active nests peaked at both WW and LG during August, but LG had lower numbers of nests than WW (Fig. 1). A second peak occurred during October/November, where both sites had similar numbers of nests (n = ~150). The number of nests at LG began to decrease from early November and reached zero in late January, while the number of nests at WW decreased from mid January and reached zero by late March. CP had very low nesting activity throughout our study.

Eggs were laid and hatched asynchronously (approximately two days apart), on average three weeks after being laid. Approximately three weeks after hatching, young ibis fledged.

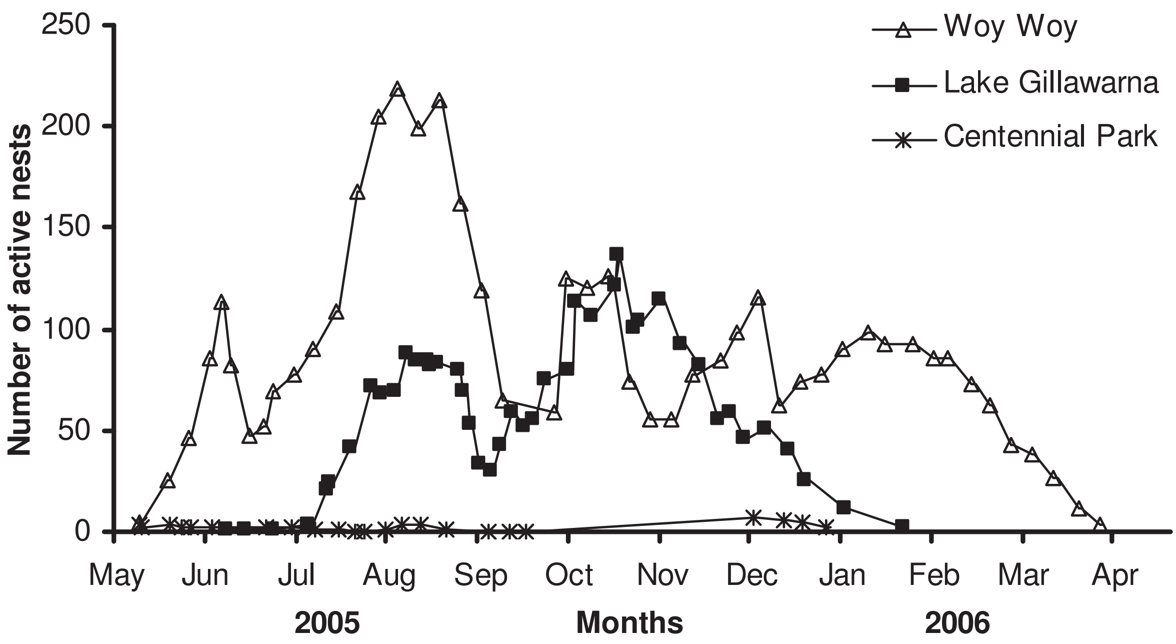


Fig. 1. Abundance of active nests of the Australian Whits Ibis during the 2005 – 2006 breeding season for Woy Woy, Lake Gillawarna and Centennial Park.

Egg sizes and weights

Freshly laid ibis eggs were always white, but often gained a dirty colour towards hatching (n = 594. Egg sizes did not differ significantly between WW (n = 275), LG (n = 262) and CP (n = 57). Mean egg lengths were similar for WW: 63.82 mm ± 0.22 s.e.; range: 53.5-79.9; LG: 63.58 mm ± 0.20 s.e.; range: 55.1-77.5; and CP: 62.54 mm ± 0.60 s.e.; range: 49.6-70.7 ($F_{2,591}$ = 3.0, P = 0.050, one-way ANOVA). The same was the case for egg widths at WW: 43.44 mm ± 0.12 s.e.; range: 32.9-47.8; LG: 43.00 mm ± 0.11 s.e.; range: 37.7-49.5; and CP: 42.81 mm ± 0.46 s.e.; range: 38.5-46.8 ($F_{2,591}$ = 4.0, P = 0.093, one-way ANOVA (Brown-Forsythe)). However, the mean egg volume at WW (61.31 mm^3 ± 0.43 s.e.; range: 21.6-80.2) was significantly larger than that at CP (58.11 mm^3 ± 1.03 s.e.; range: 45.2-86.5), neither site differed significantly from LG (59.94 mm^3 ± 0.49 s.e.; range 39.7-87.0) ($F_{2,591}$ = 5.1, P = 0.007, one-way ANOVA). Mean egg weights were significantly higher at WW (65.00 g ± 0.43 s.e.; range: 43-90) and LG (63.56 g ± 0.41 s.e.; range: 50-94) than at CP (59.55 g ± 1.06 s.e.; range: 44-80) ($F_{2,591}$ = 14.5, P < 0.01, one-way ANOVA).

Clutch sizes

Mean clutch sizes were statistically similar between WW: 2.53 eggs ± 0.03 s.e.; range: 1-5 (n = 851); LG: 2.52 eggs ± 0.04 s.e.; range: 1-5 (n = 337); and CP: 2.47 eggs ± 0.17 s.e.; range: 1-3 (n = 15) ($F_{2,1200}$ = 0.05, P = 0.95, one-way ANOVA); and ranged from one to five egg(s). Clutches with three eggs were most common at both WW (50%) and LG (53%), followed by two eggs (WW: 26% and LG: 25%) and one-egg clutches (WW: 15% and LG: 15%). A low percentage of clutches contained four (both WW and LG: 7%) and five eggs (WW: 1% and LG: >1%).

Breeding success - hatchlings

The percentage of clutches that failed to produce any hatchling(s) was higher at WW (53%) than at LG (40%). WW also produced less clutches with two and three hatchlings (20% and

11%, respectively) than LG (27% and 20%, respectively). Clutches with one and four hatchling(s) occurred at a similar level at WW (15% and 1%, respectively) and LG (12% and 1%, respectively). With a mean of 0.97 ± 0.04 s.e. hatchlings (range: 0-3), WW had a significantly lower mean number of hatchlings per clutch than LG (1.29 hatchlings ± 0.01 s.e.; range: 0-4) (t (585) = -4.36, $P < 0.01$, t-test). Hatching success at WW (38% eggs hatched) was also lower than at LG (51%).

Breeding success - fledglings

More clutches failed to produce any fledgling(s) at WW (65%) than at LG (49%). While clutches with one fledgling were as frequent at WW (13%) as at LG (14%), clutches with two and three fledglings were less frequent at WW (16% and 6%, respectively) than at LG (24% and 13%, respectively). Neither site had clutches which produced four or more fledglings.

The mean number of fledglings produced per clutch (0.63 fledglings ± 0.03 s.e.; range: 0-3) at WW was significantly less than that at LG (1.02 fledglings ± 0.01 s.e.; range: 0-3) (t (1196) = -5.95, $P < 0.01$, t-test). The mean number of fledglings produced per nest was also less at WW: 0.81 fledglings ± 0.04 s.e.; range: 0-8 than at LG: 1.59 ± 0.10 s.e.: range 0-7 (t (303) = -7.03, $P < 0.01$, t-test). With 67% of hatchlings reaching fledgling state at WW, fledging success at this location was lower than at LG (79%). Reproductive success (% eggs that hatched and fledged) at WW (25%) was also lower than at LG (40%). However, the total number of fledglings produced at WW (n = 541) was much higher than at LG (n = 343).

Growth rate of hatchlings

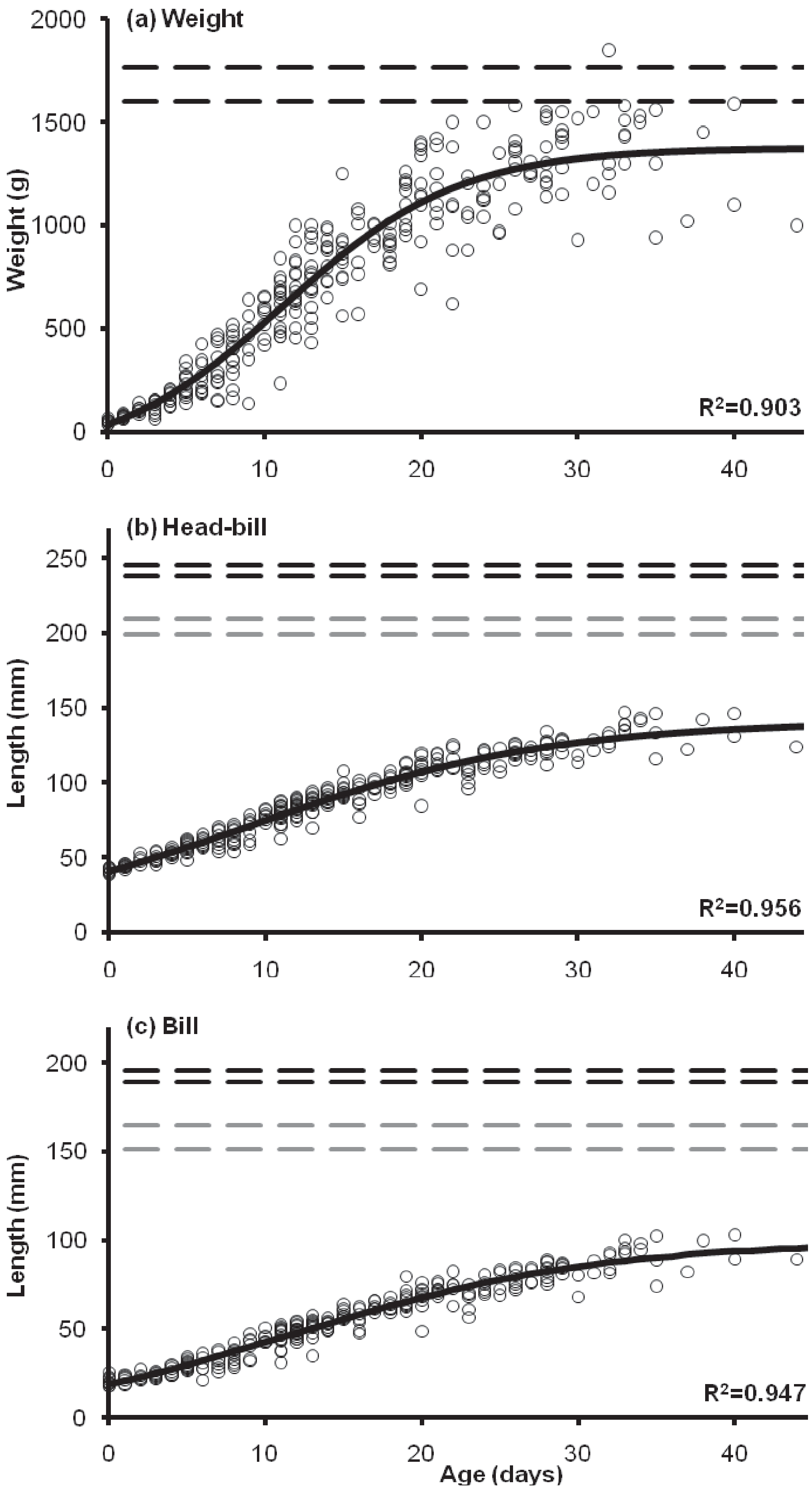
Ibis chicks hatched with a pink coloured bill and legs, black down covering their head down to their neck and light grey to white down covering the rest of their body. The chicks were often heard calling in their eggs before they hatched. On average, freshly hatched chicks (<

one hour old) weighed 54 g ± 13 s.d. They had a head-bill length of 42 mm ± 2 s.d., a bill length of 20 mm ± 2 s.d., a wing length of 22 mm ± 2 s.d., a tarsus length of 16 mm ± 3 s.d. and a tail length of 9 mm ± 2 s.d. (n = 8) (Fig. 2a-f).

The downy young began feather growth approximately one week after hatching. They took approximately 21 days to approach adult weight and tarsus length (Fig. 2a, e). Shortly before fledging, chicks weighed 993 g ± 221 s.d., and they had a head-bill length of 109 mm ± 4 s.d., a bill length of 68 mm ± 4 s.d., a wing length of 194 mm ± 18 s.d., a tarsus length of 85 mm ± 8 s.d. and a tail length of 55 mm ± 6 s.d. (n = 11) (Fig. 2a-f). Their wings and tail may require over 45 days to reach adult length (Fig. 2d, f). Head-bill and bill length did not reach adult length within the first 45 days of their life, and require additional time to reach adult size (Fig. 2b, c). Adult ibis weighed 1685 g ± 216 s.d., and had a head-bill length of 242 mm ± 7 s.d. (male) and 204 mm ± 5 s.d. (female), a bill length of 193 mm ± 6 s.d. (male) and 158 mm ± 11 s.d. (female), a wing length of 374 mm ± 19 s.d., a tarsus length of 100 mm ± 7 s.d., and a tail length of 135 mm ± 11 s.d. (n = 26) (Fig. 2a-f). All equations for the sigmoid-regressions (see Table 1. for constants ± errors) of the chicks' weight and growth increases had an $R^2 > 0.9$ (Fig. 2a-f), which indicates a strong pattern (Sokal and Rohlf 1995).

Table. 1. Estimates of the constants ± errors from the Quasi-Newton method for the sigmoid-regression lines for body weight and head-bill, bill, wing, tarsus and tail length of young Australian White Ibis between the day of hatching and up to 44 days of age. Equation for calculating the sigmoid-regression lines: y=a((exp(b(x+c))-1)/(exp(b(x+c))+1))+d (a indicates the lateral position of the curve (ie. the values where the inflection points lie), b and c determine the Y_{max} (ie. asymptote) of the equation, d indicates the specific growth rate).

Parameter	a		b		c		d	
	Estimate	± Error	Estimate	± Error	Estimate	± Error	Estimate	± Error
Weight	761.73	48.75	0.18	0.02	-11.28	0.60	614.81	31.58
Head-bill	69.73	6.90	0.10	0.01	-9.04	1.33	71.49	4.43
Bill	53.04	5.37	0.10	0.01	-11.57	1.18	46.49	2.82
Wing	163.40	7.14	0.13	0.01	-17.07	0.38	151.33	3.17
Tarsus	44.61	3.06	0.17	0.02	-9.41	0.71	47.82	2.22
Tail	59.76	4.25	0.18	0.02	-23.56	0.60	65.41	2.44


(a) Weight
Weight (g)
R²=0.903
(b) Head-bill
Length (mm)
R²=0.956
(c) Bill
Length (mm)
R²=0.947
Age (days)

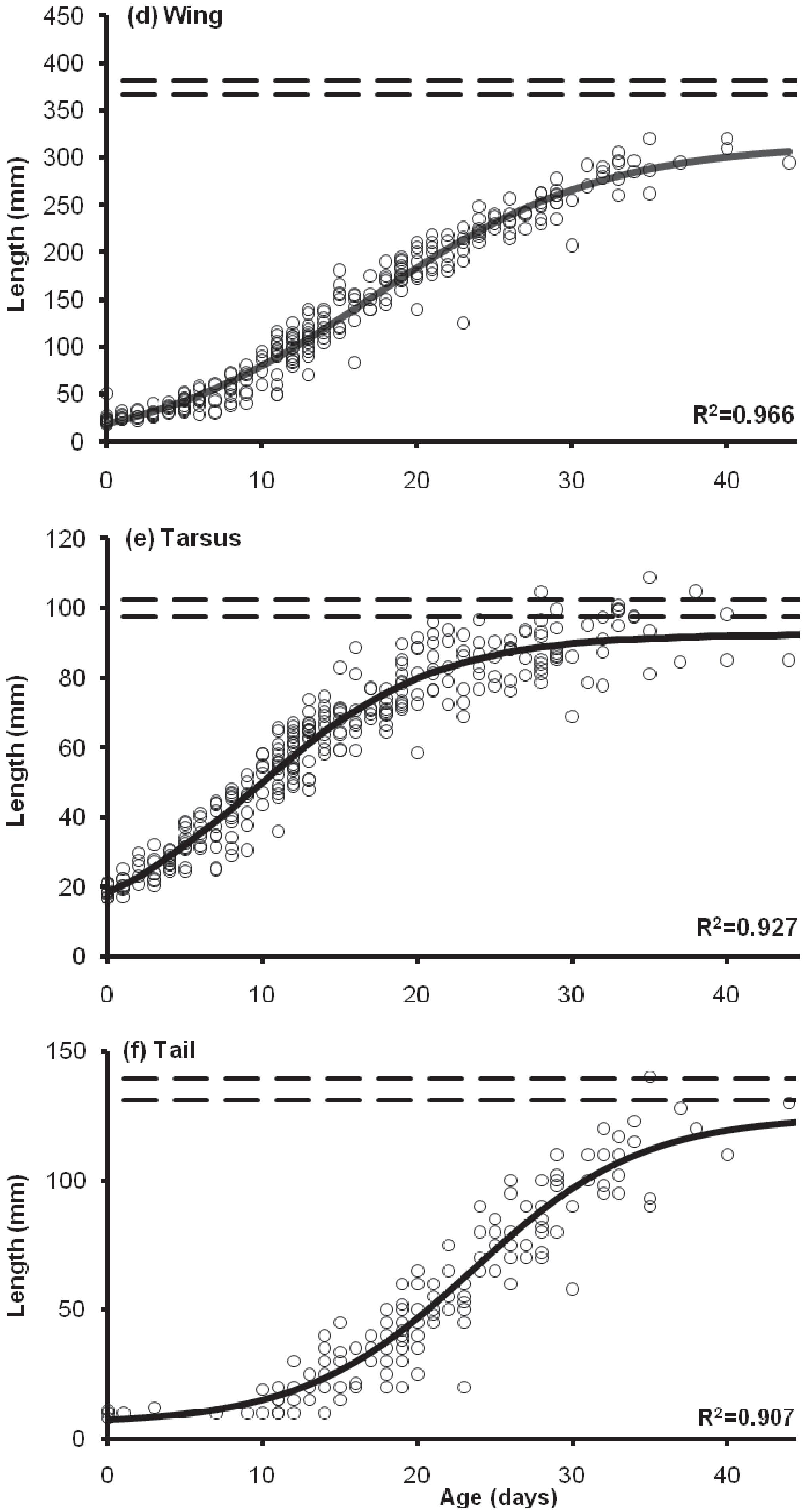

(d) Wing
Length (mm)
R²=0.966
(e) Tarsus
Length (mm)
R²=0.927
(f) Tail
Length (mm)
R²=0.907
Age (days)

Fig. 2. Body weight (a) and length of (b) head-bill, (c) bill, (d) wing, (e) tarsus and (f) tail of young Australian White Ibis between the day of hatching and up to 44 days of age (*n* = 232 chicks). Sigmoid-regression lines indicate the increase of each parameter over time (day) with the equations and R^2 values located in the bottom right hand corner of each graph. The dashed lines in each graph represent the upper and lower 95% confidence interval of each parameter for adult ibis (*n* = 26). For (b) head-bill and (c) bill, adult males (*n* = 15): black dashed lines, and adult females (*n* = 11): grey dashed lines.

Discussion

Breeding, incubation and fledging period

The Australian White Ibis bred in the urban environment during the whole year, except April, with breeding being most pronounced between June and February (Fig. 1). While the main breeding period of urban ibis (July to January) generally coincides with that of non-urban ibis, (Lowe 1984) its overall duration seems longer in the urban environment. In their traditional ephemeral environment, breeding is usually initiated by high water levels, which restricts breeding to times of heavy rain and flooding (Carrick 1962; Davis and Reid 1975; Blakers *et al*. 1984; Briggs *et al.* 1997; Kingsford and Johnson 1998; Briggs and Thornton 1999). In the urban environment ibis are generally not subjected to large fluctuations in water level. Here they often roost and nest on islands in ponds of parks (DEC 2005), whose water levels fluctuate little, and their islands usually do not fall dry. This may, in conjunction with sufficient food resources at landfills (Ross 2004; Ecosure 2009), initiate breeding the whole year round. As in non-urban colonies (Lowe 1984; Murray and Shaw 2006), ibis eggs hatched three weeks after laying and young fledged roughly three weeks later.

Egg sizes and weights

The egg volumes of our ibis were similar between sites (means: 58.1 and 61.3 mm^3) and to those of other urban colonies (means: 59.6 and 63.4 mm^3) (Murray and Shaw 2006; Thomas 2007), but were smaller than those from non-urban colonies (mean range: 64.7-65.2 mm^3) (Lowe 1984). Differences were particularly pronounced in the eggs' lengths, with eggs from our (mean range: 62.9-63.8 mm) and other urban colonies (mean range: 63.6-64.3 mm) (Murray and Shaw 2006; Thomas 2007) being much shorter than those from non-urban colonies (mean range: 66.3-67.1) (Lowe 1984). A reduction in egg volume could reduce the hatching weight of the chicks and thus reduce their chances of fledging (Auman 2008). It is not known why eggs in urban environments are smaller. Extensive feeding on a poor diet from landfills (Murray and Shaw 2006) could be one reason for smaller eggs. This was also found in Silver Gulls (*Larus novaehollandiae*) that fed extensively from landfills instead of natural environments (Auman 2008). Ibis from Sydney carry high levels of lead, mercury, dioxins, dioxin-like compounds and brominated flame retardants (Burger and Gochfeld 1999; Edge 2008), which can cause behavioural abnormalities and increase mortality (Burger and Gochfeld 1999; Edge 2008). Whether these substances are also associated with small egg sizes and the severe leg deformities (in all cases fatal) we found in some chicks is not known (per. obs.), and needs to be addressed in further research.

Clutch sizes

In general, mean clutch sizes at all colonies were similar to each other and also corresponded to those recorded in previous studies on these (Thomas 2007; Corben and Munro 2008) and other urban colonies (Movieworld, Queensland (2.46 eggs ± 0.71 s.e.) (Murray and Shaw 2006); and Winter Swamp, Victoria (2.25 eggs ± 0.05 s.e.) (Kentish 1999)), but were considerably smaller than those at non-urban colonies (mean range: 2.65-3.21 eggs) (except for Heifer Swamp, Victoria) (Lowe 1984). In other studies of urban and non-urban bird populations, clutch sizes were either significantly larger (Tortosa *et. al*. 2003) or smaller in urban areas (Pierotti 1982), or did not differ between sites (Duhem *et al.* 2002; Auman 2008), which suggests that birds living in the urban environment do not follow a common trend. This is of little surprise. Requirements of species (and probably individuals) as well as urban environments vary in numerous ways (Breuste *et al.* 2008). So while some species may profit from urban environments, others may be disadvantaged. In the case of the ibis, urban birds had smaller clutch sizes. This may be, as with egg size, associated with an inadequate diet (Martin 1987), but could also be linked to the birds' age (young birds often produce smaller clutches); different climate conditions in coastal Australia (Klomp 1970); and other factors specific to the urban environment (e.g. high pollution levels).

Three-egg clutches were most common in this and all other studies on urban (Kentish 1999; Corben and Munro 2006; Murray and Shaw 2006; Thomas 2007) and non-urban ibis (Lowe 1984). Five-egg clutches were rare, but occurred at both of our colonies, as well as Winter Swamp, Victoria (Kentish 1999) and Healesville, Victoria (Lowe 1984) (≥1% of all clutches). These and even larger clutches may be the result of some ibis inflating clutch sizes by transferring eggs between nests (see chapter 3). This has also been suggested for the American White Ibis (*Eudocimus albus*) (Frederick and Shields 1986; Shields 1987).

Breeding success - hatchlings

We found large differences in the amount of clutches that failed to hatch young between sites. Also the mean number of hatchlings per clutch and hatching success (% eggs that hatched) differed. This means that urban colonies can differ considerably in their reproductive output. This needs to be considered when studying and managing ibis. The common approach to study a single colony and use it as a representative for other colonies, is not appropriate for ibis. Instead, several ibis colonies need to be studied to understand the reproductive biology of ibis and obtain appropriate baselines for management. Possible reasons for eggs failing to hatch may include: desertion by adults, egg infertility, and exposure to unfavourable weather, predation and/or high toxin levels in the eggs (Thomas 2007). At WW, nests were occasionally destroyed during king tides and eggs were taken by Australian Ravens (*Corvus coronoides*). To which extent these two factors have influenced hatching success was not investigated. However, in other studies on urban ibis, these factors were assumed to cause egg mortality (Murray and Shaw 2006; Thomas 2007; C. Legeo

(NPWS) per. comm), and are likely to be important. Nest monitoring during incubation and studies of unhatched eggs are needed to identify the reasons for eggs failing.

The mean number of hatchlings per clutch at our colonies (WW: 0.97, LG: 1.29 hatchlings) was similar to that at other urban colonies (means: 0.7 and 1.2 hatchings) (Murray and Shaw 2006; Thomas 2007). The same was true for the overall hatching success at our (WW: 38 %, LG: 51%) and other urban colonies (mean: 38 and 48%) (Murray and Shaw 2006; Thomas 2007). However, all urban colonies (except maybe LG) had a lower hatching success than that of non-urban colonies (55-60%) (Lowe 1984). Unfortunately, Lowe (1984) did not calculate the mean number of hatchlings per clutch to allow us to directly compare his results to ours. Nevertheless, it appears that urban sites produce less hatchlings than non-urban sites. This coincides with studies on urban Herring (*Larus argentatus*) and Ring-billed Gulls (*L. delawarensis*) that feed from landfills and hatch less young than birds from natural environments (Belant *et al.* 1998).

Breeding success - fledglings

The mean number of fledglings per clutch and nest, fledging success (% hatchlings that fledged) and reproductive success (% eggs that hatched and fledged) also differed between our colonies, with LG being the most successful colony. This highlights again that colonies can differ and that management baselines need to be derived from detailed studies of several colonies.

The fledging success (WW: 65%; LG: 79%) and mean number of fledglings per clutch at our colonies (WW: 0.63 fledglings; LG: 1.02 fledglings) were generally higher than those at another urban (mean: 60%) (Murray and Shaw 2006) and non-urban colonies (mean range: 0.34-0.76 fledglings) (Lowe 1984). Unfortunately, Murray and Shaw (2006) did not provide the mean number of fledglings per clutch and Lowe (1984) did not present fledging success, so direct comparisons are not possible. The reproductive success at both WW (25%) and LG (40%) and another urban colony (mean: 29%) (Murray and Shaw 2006) was higher than that at non-urban colonies (mean range: 18-26%) (Lowe 1984), which suggests that urban ibis have at least a similar, if not even higher, reproductive output than non-urban colonies. This may be mainly due to the higher amount of hatchlings surviving to the fledging stage. Other species that feed from landfills, and have increased their fledging success include: the White Stork (*C. ciconia*) (Blanco 1996; Johst *et al.* 2001; Tortosa *et al.* 2002; Massemin-challet *et al.* 2006) and several gulls (Belant *et al*. 1998; Yorio 2002). Landfills can also be important feeding sites for juvenile birds and can increase survival rates, as it has been reported for the Common Raven (*Corvus corax*) (Webb *et al.* 2004).

Reproductive productivity cannot alone predict a population's status and its change. Reliable predictions are only possible when mortality rates are known (Gotelli 2001). Unfortunately, mortality data for ibis are limited. Banding records suggest a lifespan of up to 26 years of age (ABBBS, Canberra) and mortality rates of 37% for first year and 24% for two to nine year old birds (Lowe 1984). Since these mortality rates are based on records from non-urban ibis studied between 1956-1968 (Lowe 1984), they may differ to those of urban ibis today, and therefore cannot be used for predicting the behaviour of urban ibis populations. Further research needs to concentrate on the mortality rates of ibis from both the urban and non-urban environment.

Growth rate of hatchlings

This study is the first to describe the growth of ibis from hatchlings to adult size (Fig. 2a-f). All morphological parameter measurements reached or were close to the adult size range when the chicks were around 30 days old, except for the head-bill and bill length (Fig. 2b, c). This coincides with findings from Carrick (1962), which suggest that young birds need three months to reach the head-bill length of adults. Similar applies to the American White Ibis

(*Eudocimus albus*), here young birds need approximately 72 days for their bill to reach 90% of its adult size (Kushlan 1977). Since the head-bill length of the birds took the longest time to grow (Fig. 2b), it probably is the best indicator of age during the first two months after hatching, and before it reaches female length.

During our study, it became increasingly difficult to capture older chicks as many of them were able to fly. This decreased the sample size of older chicks, but probably also biased our results towards chicks that were weak fliers. Most chicks captured at an age of 28 days and older had protruding keel bones, which can indicate malnourishment (Gregory and Robin 1998). This hindered flight and allowed for easy capture. Many of these chicks were dead in the following weeks, which suggests that weaker chicks were sampled during this stage.

Conclusion

In summary, we found large differences in the breeding success of the Australia White Ibis between our colonies and other urban (Murray and Shaw 2006) and non-urban colonies (Lowe 1984), which will need to be taken into account when managing this species. While overall reproductive success appears high in urban environments, the lack of information on the bird's mortality makes it difficult to predict the behaviour and further development of urban ibis populations. Further research needs to focus on this aspect. In any case, since ibis may travel to the urban environment for breeding from inland Australia (Thomas 2007; Corben and Munro 2008), where breeding is difficult due to drought, river regulation, and declining wetlands (Kingsford and Johnson 1998), urban managers need to be careful. They need to be aware that management may not only affect urban ibis, but also birds that originate from areas where the species is in decline (Corben and Munro 2008). This needs to be taken into account when managing this protected native species (*Nature Conservation Act* 1992 and *Native Species Act* 1994), so that its survival is ensured.

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Chapter 3.

From one nest to another: active transfer of eggs between nests of the Australian White Ibis (*Threskiornis molucca*).

Abstract.

In a breeding colony of the Australian White Ibis (*Threskiornis molucca*) we discovered clutches containing eggs from other ibis clutches. Of the 1017 ibis clutches monitored over the 2005/2006 breeding season, 4.7% clutches gained eggs and 5.4% clutches lost eggs. One nest both received and lost eggs to another nest. While some of the displaced eggs may have been knocked or rolled into neighbouring nests by ibis, this does not explain the large number of repositioned eggs. Some eggs had moved over considerable distances (up to 5 m) or were discovered in nests with much higher nesting platforms than those of the nests the eggs originated from, which makes it unlikely that eggs were displaced accidentally or rolled by the birds into their nests from the ground. Since we observed an ibis carrying an egg in its bill, it is likely that the birds themselves transferred eggs between nests.

Introduction

Strange eggs in a nest are mainly due to brood (or nest) parasitism (Payne 1977). Brood parasitism occurs in many species of birds (Payne 1977), fishes (Johnston 1994) and insects (Wang and Horng 2004). This behaviour allows animals to avoid the parental responsibilities of incubation and rearing of hatchlings, thus reducing their energy requirements for reproduction (MacWhirter 1989). In birds, the most common form of brood parasitism is when an egg is laid directly into another bird's nest, which is commonly referred to as 'egg dumping' (Payne 1977). Brood parasitism can occur in two forms: intraspecifically (within the same species) or interspecifically (between different species). Intraspecific brood parasitism is considered to be more widespread (2.4% of all birds) than interspecific brood parasitism (Yom-Tov 2001). Most avian intraspecific brood parasites are colonial breeders (57.5%) (Rohwer and Freeman 1989; 1992; Sorenson 1992; Beauchamp 1997; Geffen and Yom-Tov 2001), probably because not only the high nest availability, but also egg laying, feeding and parenting required for successful intraspecific brood parasitism are highly synchronised among these birds (Hamilton and Orians 1965; Payne 1977; Yom-Tov 1980; Andersson 1984; MacWhirter 1989). Intraspecific brood parasites are also more common in precocial than altricial birds, since the energy requirements for parental care (e.g. feeding) are higher in the latter (Rohwer and Freeman 1992). The majority of obligate interspecific avian brood parasites are non-colonial and altricial (see Hamilton and Orians 1965; Rothstein 1990; Lyon and Eadie 1991; Robert and Sorci 2001).

There are other breeding systems in birds that produce combined clutches (eggs from more than one female). In Emus (*Dromaius novaehollandiae*) (Taylor *et al.* 2000) and other struthioniformes (Handford and Mares 1985), several females lay eggs into one nest producing large combined clutches, which are cared for by the male. Also female Laysan Albatrosses (*Phoebastria immutabilis*) can pair up, lay into one nest and breed successfully (Young *et al.* 2008). Geese (Kalmbach 2006) and pelicans (Vestjens 1977; McTaggart unpub. data) on the other hand, roll either their own or foreign eggs into their nests, when they find them in the immediate vicinity of their nests. Directly carrying and transferring eggs between nests is rare, but may exist in two species of corvids (Trost and Webb 1986) and swallows (Weaver and Brown 2004), and the American White Ibis (*Endocimus albus*) (Shields 1987). Shields (1987) reported five instances, where eggs had moved over considerable distances and assumed that these ibis carried eggs in their bill to other nests. However, the author never observed the birds transferring eggs (Shields 1987), and therefore could not verify his view. Here we provide evidence that the Australian White Ibis (*Threskiornis molucca*) is able to carry its own eggs and may directly transfer eggs between nests.

Method

Study animal

The Australian White Ibis (*Threskiornis molucca*) (from now on referred to as ibis) is a colonially breeding waterbird, native to Australia and the southern parts of Papua New Guinea (Marchant and Higgins 1990). Ibis mainly bred and roosted in the inland wetlands of Australia (Carrick 1962). However, they have expanded their geographical range since the 1970's and are now common in urban coastal regions, where they breed (Corben and Munro 2006) and feed on landfills (Ross 2004). Ibis are generally monogamous, but can change partners between clutches (Beilharz 1988). Their clutches usually contain one to four eggs, which hatch after three weeks (Lowe 1984). In non-urban environments ibis breeding is triggered by the flooding of wetlands (Carrick 1962).

Study site

The study was conducted on a mixed breeding/roosting colony of approximately 1000 ibis and 500 pelicans on a sand island (32°30'S, 151°20'E) within the Brisbane Water estuary near Woy Woy (~80 km north-north-west of Sydney's centre, NSW). Public access to the island is prohibited, so that breeding pelicans are not disturbed (DECC, Gosford). The size of the island (0.10 to 0.50 ha) varied depending on tidal levels. During king tides and severe storms large parts of the island flood (pers. obs.). The island was sparsely vegetated, with some grassy patches and a small number of dead trees. All ibis nests were erected directly on the ground or on fallen down branches of dead trees. Nests were constructed from sticks and leaves, and varied in height (0.02 to 0.5 m). Australian Ravens (*Corvus coronoides*) were the main predators of ibis on the island. They usually took eggs and hatchlings from unattended nests, but also killed weak fledglings (per. obs.).

Data collection

The island was visited once per week between 1 April 2005 and 1 April 2006. During these visits, all active ibis nests (i.e. nest with eggs or chick) were individually marked with coloured cattle tags (Leader Product, Craigieburn, Australia) and numbered. Overall, 1017 clutches were monitored, with eggs individually labeled with a xylole-free (non-toxic) felt pen (Artline - Garden Marker Black 780, Gold Coast, Australia). The content of each nest was recorded during each visit to the island, which allowed us to determine the clutch size, hatching and fledging success, and whether eggs were missing or had changed nests.

Data analysis

We calculated the number of clutches that lost or gained eggs, and their representation (%) in the whole colony (n = 1017 clutches). We also determined the most common number of eggs that were both gained and lost from clutches, and the percentages of clutches that this occurred in. For clutches that had gained several eggs, we calculated which percentage of them had received eggs from multiple nests.

For the clutches that had gained eggs, we calculated their mean clutch size ± standard error (s.e.), and range and mode (%), firstly without gained foreign eggs (original state), and secondly with gained foreign eggs (original number of eggs plus added eggs). We also calculated the mean clutch size ± s.e., range and mode (%) of ibis clutches that neither lost or gained eggs from other nests. A Mann-Whitney U test was used to test whether this mean clutch size differed significantly from those of nests that had gained eggs (both in their original state and with transferred eggs).

The most common clutch size, and number and mode (%) of eggs lost were calculated from clutches that had lost eggs. We also determined the hatching success (% eggs that hatched from all clutches) for the clutches with lost (n = 48) (not including moved eggs) and gained eggs (n = 55), and all other clutches in the colony (n = 1017). None of the displaced eggs (with one exception) was recorded on the ground before it was found in another nest.

Results

During our study of 919 ibis clutches (2345 eggs), we discovered 72 eggs that originated from other nests. Displaced eggs were found throughout the entire breeding period of ibis (mid May 2005 to early April 2006), and there was no time when displaced eggs were more common or absent. 48 clutches (4.7% of all clutches) received eggs from 55 clutches (5.4% of all clutches). One nest both received and lost eggs to another nest. The number of eggs that was added to clutches varied (see Fig. 1). In most cases (69%) only a single egg was added to a clutch, but up to four foreign eggs were found in a clutch. Of the nests that received more than one egg, 60% gained eggs from several nest (up to four different nests). One nest had nine eggs, with three of them originating from two other nests. It is not known whether this nest has had an original clutch of six eggs or contained already eggs from another nest.

Fig. 1. An ibis nest with three eggs. Two of these eggs originate from foreign nests. The labels on the eggs indicate in which nest (number) and sequence (letter) they were laid.

The mean original clutch size of nests that gained eggs (2.77 eggs ± 0.18 s.e.; n = 48 ; range: 1-6; mode: 3 (45%)) did not differ significantly from normal clutches (U = 13783, Z = -1.175, P = 0.240, Mann-Whitney U test), while the mean clutch size after the addition of eggs (4.23 eggs ± 0.21 s.e.; n = 48 ; range 1-9; mode: 4 (32%)) was significantly larger than those in normal nests (2.53 eggs ± 0.03 s.e.; n = 851; range 1-5; mode: 3 (50%), n = 851 clutches) (U = 4624, Z = -8.63, P < 0.001, Mann-Whitney U test). Despite their extra eggs, the hatching success of nests that gained eggs (48%) was higher than that of other nests in the colony (38%). While in most cases we could not establish whether any of the added eggs had hatched, in two cases this was likely (i.e. all eggs of those two nests had hatched).

43 out of 49 clutches (87%) lost one egg to another clutch. However, some clutches lost eggs to several other nests. One nest contained three eggs of its original clutch and all three eggs from another ibis nest. In later weeks, two of these eggs were found on the ground, then one of these eggs was discovered back in its original nest, and then disappeared altogether. Once a nest had lost (an) egg(s) these eggs were usually not replaced. Only three nests contained a new egg after losing an egg in the preceding week. Most nests that lost one or more eggs (53%) had a clutch size of three eggs (before losing eggs) and a hatching success of 25% (not including moved eggs).

The distances that eggs had moved varied between 0.3 and one meter, but some extended up to five meters. In most cases it was unlikely that the displaced eggs were knocked or rolled into other nests, since most nests had high off the ground nest platforms, with clear gaps separating individual nests. Several eggs (n = 12) from low nests were later recorded in nests with a very high nest platform, which further argues against an accidental displacement of eggs. On the 8 November 2005, an ibis was observed holding an egg in its bill, standing upright over a nest before placing the egg down. Thus, ibis are able to carry their own eggs and potentially can move them into other nests.

Discussion

This study shows for the first time that unusually large clutches (above four eggs) of the Australian White Ibis are not necessarily the result of some birds laying large clutches (see Beilharz 1988, Kentish 1999), but foreign eggs being added to the original clutches. There are many accounts in the literature that describe foreign eggs in nests (Yom-Tov 2001). Eggs can either roll or be knocked accidentally into other nests (Janson 1953; Johnson and Kirsch 1977; Blohm 1981). They can also be added by brood parasites (through egg dumping)

(Payne 1977). In the ciconiiformes, brood parasitism is common and occurs interspecifically in the Great Egret (*Casmerodiuys albus*) and Black-crowned Night Heron (*Nycticorax nycticorax*) (Cannell and Harrington 1984), and intraspecifically in the Purple Heron (*Ardea purpurea*), Squacco Heron (*Ardeola ralloides*), Reddish Egret (*Egretta rufescens*) (Gonzalez-Martin and Ruiz 1996) and Maguari Stork (*Ciconia maguari*) (Thomas 1984).

Accidental displacement is unlikely for ibis, since the eggs were often moved over large distances (up to 5 m) and into nests with higher nest platforms than those of the original nests of the eggs. Egg dumping (laying into foreign nests) can also be excluded, since eggs were moved after labeling and therefore after laying. Initially it was difficult to explain how eggs had moved between nests. However, when we observed an ibis carrying an egg in its bill and putting it into a nest, we were convinced that the birds were transferring eggs between nests. Our view was strengthened, when we scanned the literature for similar findings and discovered that other species have been recorded picking up their own eggs and/or have been suspected to move them into other nests. They include the: Little Blue Heron (*Egretta caerulea*) (Rodger 1978); Black-billed Magpie (*Pica pica*); Pinyon Jay (*Gymnorhinus cyanocephalus*) (Trost and Webb 1986); Mallard Duck (*Anas platyrhynchos*) (Avitabile 1969); and American White Ibis (*Eudocimus albus*) (Shields 1987); and possibly Chuck-will's-widow (*Caprimulgus carolinensis*) (Audunon 1831; Ganier 1964; Jackson 1985). Shields (1987) reported that eggs of the American White Ibis were found in nests that were considerable distances away from their original nests, which led him to propose that they had been displaced by the birds. However, he never observed any ibis carrying eggs, which weakens his evidence.

There are two possibilities of how our ibis may have moved their eggs. The eggs were either moved into another nest by their original owner, or collected by other ibis from foreign nests and placed into their own nest. Moving own eggs into a foreign nest may suggest intraspecific brood parasitism, which is common in colonial breeders (Yom-Tov 2001). Since laying and egg development is often synchronised in ibis colonies (Lowe 1984; unpub. data), which favours intraspecific brood parasitism, displacing eggs into foreign nests may increase the reproductive output of some birds (Yamauchi 1993). Unfortunately, we could not assess the hatching success of our ibis eggs, and only in two cases we were able to determine that eggs had hatched. It is interesting that the hatching success of clutches with added eggs (48%) was much higher than both normal clutches (no eggs added) (38%) and clutches with lost eggs (25%) in the colony. This suggests that eggs from clutches with a low hatching success were transferred to nests with a higher hatching success, where they may have had a better chance of hatching.

The second scenario, whereby an adult collects another bird's egg and places it into its own nest, seems at first sight of no advantage. However, this behaviour has been observed in other species, such as the Australian Pelican (Vestjens 1977; L. McTaggart pers. comm.) and geese (Kalmbach 2006). These birds roll foreign eggs into their nest, when they find them in the vicinity on the ground. While we recorded many eggs of ibis on the ground, none of them was moved into a nest. Also none of the labelled eggs (with one exception) were found on the ground before they were moved, which argues against the birds rolling eggs into their nest. It is, possible that ibis have collected them from adjacent nests and carried them into their own nest. The ibis may have, like pelicans (Vestjens 1977), been mistaken about the eggs ownership and simply considered them as their own and transferred them into their nests. However, since ibis are altricial, such behaviour would be most likely detrimental to the fledging success of their own young. While Corben and Munro (2006) have reported that ibis can produce up to four fledglings from a single clutch, Lowe (1984), who experimentally increased clutch sizes from two to four eggs, did not find any clutches with more than three fledglings, which was also common in unmanipulated clutches. Therefore the number of fledglings per clutch seems to be limited, and adding foreign eggs into its own nests seems at first sight of little advantage. However, there may be another advantage. At our island, predation on eggs and nestlings by ravens was considerable, and probably was the most significant factor for egg and chick losses. It appears possible that by increasing clutch sizes with foreign eggs, the probability of losing its own eggs was reduced and ensured that more offspring of the bird's original brood survived.

Our findings are unique, raise many questions, and open a whole new avenue of research. In the past, it has occasionally been suggested that birds can carry their own eggs and move them between nests (Shield 1987). However, in general these suggestions were not taken seriously and disregarded by researchers, because they considered such behaviours unlikely for birds (e.g. Jackson 1985). In the case of the ibis we have now considerable evidence that egg transferals occur and need to be studied further. In particular, we need to expand our investigations to other colonies, determine how eggs are transferred and the reasons for this, and conduct genetic tests to identify the relatedness of chicks and breeding adults to each other.

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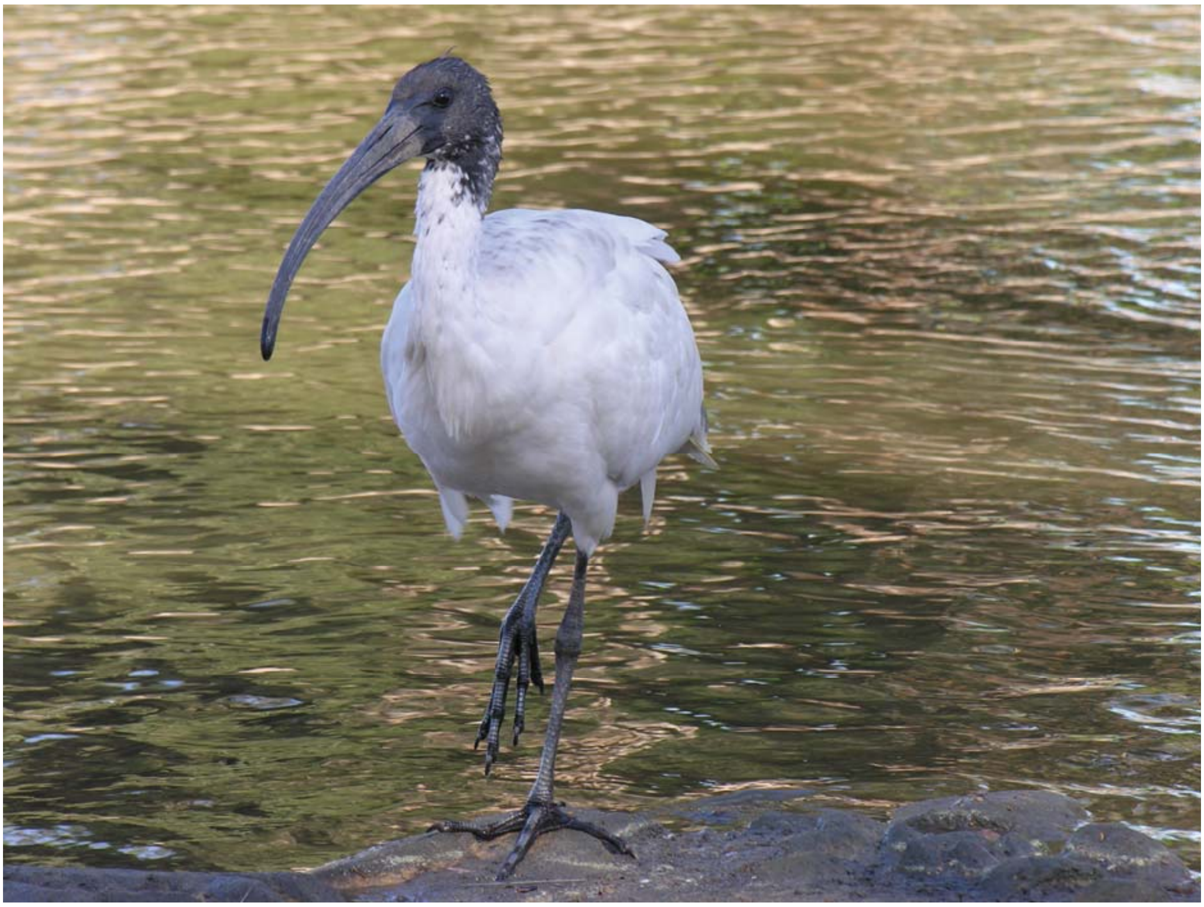
Population dynamics of the Australian White Ibis (*Threskiornis molucca*) in the urban environment.



Abstract.

The Australian White Ibis (*Threskiornis molucca*), a native colonial waterbird, has since the 1970's increased dramatically in coastal urban environments, where its abundance conflicts with human interests. The public and many agencies with ibis problems demand a rigorous reduction in population sizes. However, since little is known about the populations of urban ibis, baseline information for appropriate management is lacking. Here we present data on ibis abundances and age composition of three major ibis colonies from Sydney, Australia, over one year. We found large differences between colonies and over time, which highlights that more than one colony needs to be studied to obtain a solid baseline for management plans. The total roosting population at two sites was highest during June-July and February-March, and lowest during October/November, while at the third site, it peaked during December-January. Juvenile abundances were generally high during December-January (end of breeding season), and decreased towards March as they left the site. An analysis of the preferred fly-in directions into their overnight roosts suggests that many ibis forage at local landfills.

Introduction

In recent years, several species of ibis have become exotic invaders (e.g. Sacred Ibis (*Threskiornis aethiopicus*) in Europe (Clergeau and Yésou 2006) and Florida, USA (Herring and Gawlik 2007)) or expanded their breeding ranges (e.g. Sacred Ibis (Kopij 1999) and Hadada Ibis (*Bostrychia hagedash*) (Macdonald *et al.* 1986) in South Africa; Australian White Ibis (*T. molucca*) in Australia (Bekle 1982; Ross 2004)). These invasions and expansions often have ecological, social and economic consequences (Mack *et al.* 2000; Ross 2004; Corben and Munro 2008) and require management. This is, however, often difficult, because baseline data on population abundances and structure are lacking (Thomas 2007; Corben and Munro 2008). The Australian White Ibis (referred to as ibis from here on), a bird native to Australia (Marchant and Higgins 1990), which traditionally breeds in the wetlands of inland Australia (Carrick 1962; Cowling and Lowe 1981; Lowe 1984), is a example of this. Since the 1970's, it has undergone a major range expansion by extending its range into coastal areas, where it breeds in large colonies in many urban environments (Bekle 1982; Ross 2004; Murray 2005; Thomas 2007). The public and many agencies with ibis problems currently demand an immediate reduction in ibis numbers (DEC 2005; Ecosure 2009). However, appropriate management is difficult, since little is known about urban ibis (Corben and Munro 2008).

Although ibis can be found year round in urban centres in Australia, there is some evidence that their abundances fluctuate daily (Holmsten 2003) and seasonally (Corben and Munro 2008). Corben (2003) hypothesised that the daily fluctuations in abundances were due to local movements. Since seasonal abundances were much higher during the breeding period than at other times, Corben and Munro (2008) further suggested that large numbers of ibis move into the urban environment for breeding and that these birds may originate from inland Australia, where numbers are currently declining (Porter *et al*. 2006). While a recent large-scale abundance survey of New South Wales (NSW) and southern Queensland (QLD) (Thomas 2007) supports this view, Corben and Munro's (2008) study focuses on only a single roosting/breeding site (Centennial Park, Sydney) over half a year. For a more robust analysis it is essential to monitor several sites over at least one year, so that it can be determined whether population increases in urban environments are not just isolated events. Therefore, the aim of this study is to identify changes in abundances and age composition (another important factor for management) of ibis at three major urban roosting/breeding sites over one year. During this study we also took the opportunity to determine the fly-in directions of ibis into their roosts with the intent to identify their potential feeding sites in the urban environment. Our findings represent the most comprehensive description of the population dynamics of urban ibis and provide baselines for the development of management plans for this and related species, such as the Sacred Ibis in Europe and North America (Clergeau and Yésou 2006; Herring and Gawlik 2007).

Methods

Study animals

The Australian White Ibis is endemic to Australia, the southern areas of Papua New Guinea and some of the surrounding islands (Marchant and Higgins 1990). It is closely related to the Sacred Ibis from Africa, and was until recently regarded as this species (Lowe 1984; Lowe and Richards 1991). The Australian White Ibis traditionally nests and roosts near water bodies and on small islands of the inland wetland systems of Australia (e.g. Murray-Darling river system (Carrick 1962)). Ibis have been first recorded breeding in coastal urban environments (Sydney) in the 1980's (Morris 1983). The species is gregarious (Ross 2004) and can form large colonies of up to over 10,000 individuals (Carrick 1962). In general, ibis are monogamous, but can change partners between clutches and even mate with different partners, while incubating or rearing their own clutch with their partner (Lowe 1984). Once ibis fledge they can fly large distances (from Victoria (Australia) to southern Papua New Guinea (Carrick 1962; Purchase 1976)). Today ibis are very common at urban parks and landfills of Australia, which are used as feeding sites (Ross 2004). Ibis have been reported breeding in the urban environment between June and January (Corben and Munro 2008).

Study sites

The study was conducted at three urban colonies in the wider Sydney area (NSW, Australia). The colonies were located at: (a) Centennial Park (CP) (33°32'S, 151°8'E), an urban park (360 ha) in eastern Sydney; (b) Lake Gillawarna (LG), Bankstown (33°32'S, 150°35'E), an artificial wetland in western Sydney; and (c) a sand island in the Hawkesbury River estuary within Brisbane Water, near the town of Woy Woy (WW) (32°30'S, 151°20'E, ~80 km NNE of Sydney's centre). All colonies were confined to small islands (0.04 ha at CP, 0.45 and 0.03 ha at LG (two islands) and 0.10 - 0.50 ha (depending on tidal levels) at WW), which were surrounded by water throughout the entire breeding period. All sites were close to (<25 km) landfills for domestic waste, which were regularly used by ibis for foraging and roosting. The island at Woy Woy also contained a large breeding colony of at least 500 Australian pelicans (*Pelecanus conspicillatus*).

Data collection

All three ibis colonies were visited and surveyed once per week on different days (156 visits in total) between 1 April 2005 and 1 April 2006. No surveys were done on days of heavy rain. All surveys were conducted with binoculars (10 x 40 magnification, Zeiss, Germany) and a spotting scope (77 mm, Leica Televid, Germany).

Roosting population size

In order to get an accurate measure of the total roosting population of ibis, firstly the numbers of ibis on each roosting island were counted two hours before dusk. Then all ibis that were flying into or leaving the roost were counted. This was done from one spot, which allowed us to view all arriving and departing birds. Counts for each island started two hours before sunset and finished just after sunset (dusk) (see Corben 2003, for details). The counts started ~15:30 h in winter and ~17:30 h in summer. The total roosting population was calculated by adding the number of ibis on the island at the beginning of the count to the number of ibis that flew onto the island minus the total number of ibis that flew off the island during that count.

Age composition

Since it was impossible to identify age compositions during the fly-in counts (see previous section), we used Corben's (2003) approach for determining age classes. This included weekly abundance counts of juveniles and adult birds (for descriptions, see Marchant and Higgins 1990) in the late afternoon at each site. Only juveniles that had already fledged were included, since numbers of nestlings were difficult to estimate accurately. All counts were completed two hours before sunset, as this is the best time for determining age composition (Corben 2003). We used line transects (along the length of each pond) at CP and LG and spot counts from a jetty (approximately 200 m NW of the roosting island) at WW. The surveys did not disturb the birds. Age composition could not be determined at WW during October to November 2005 due to a broken scope.

Fly-in preference

The arrival direction of each ibis arriving at its roost during the evening was recorded, and assigned to one of the 45° sectors of a compass (i.e. N, NE… and NW). Ibis typically arrived in flocks at high altitude (>50m) and descended straight onto the islands during the evening, thus we were able to distinguish between birds travelling from distant locations and birds moving locally.

Data analysis and statistics

From the weekly counts of the total roosting populations, and the adult and juvenile populations two-monthly means (± s.e.) were calculated for each sample group. One-way repeated measures ANOVAs (Wilks' Lambda) were conducted to compare the means of each sample group (total roosting, and adult and juvenile population size) over one year (= six two-monthly sampling intervals). These were followed by Bonferroni Pairwise Comparisons, if differences needed to be identified. Homogeneous variance was determined by the Levene's test. The above tests were conducted using the SPSS software package (Version 14.0) and were assessed at a $P = 0.05$ significance level.

To identify any directional preference in the fly-in directions of ibis into their roosts, we firstly calculated the total number of ibis arriving from each direction (= total number per 45° sector) for each weekly survey. We then calculated the mean number of ibis arriving from the same direction (45° sector) for each month and site**.** Since the monthly means per 45° sector were statistically similar for each site ($P > 0.05$, Watson's F-test (Batschelet 1981)), we calculated annual means for each site (Oriana, Version 2.0, Kovach Computer Technologies). Since ibis numbers arriving at each site differed, we converted total numbers into percentages, so that we could compare between sites (Fig. 3). Since the directional preferences of the ibis at CP were strongly uni-modal, we also calculated the vector length (r) of their mean arrival direction (α) and variance (v), and tested it against randomness with the Rayleigh test (Batschelet 1981). No tests were performed for the other sites, since the orientation of the birds was not uni-modal. A one-way repeated measures ANOVA (Wilks' Lambda) was used to detect any significant differences in the percentages of ibis arriving from each direction. This was followed by Bonferroni Pairwise Comparisons to identify the source of difference. The fly-in data are displayed in rose-diagrams (unit circles) (Oriana, Version 2.0, Kovach Computer Technologies) superimposed on the geographical locations of the breeding sites using the ArcGIS mapping program (Version 9.2) (Fig. 3). The map template was obtained from Geoscience Australia (2008).

Results

Roosting population size

Between April 2005 and April 2006, the mean roosting populations at CP, LG and WW ranged between 190 and 394, 203 and 777, and 630 and 1033 birds, respectively (Fig. 1). Time had a significant effect on the abundances of all three populations (CP: $F_{5,3} = 151.90$; LG: $F_{5,3} = 697.94$; and WW: $F_{5,3} = 30.94$, $P < 0.01$ for all comparisons, repeated measures ANOVA (Wilk's Lambda)). While the population at CP was much smaller than that at WW, both populations decreased in abundances from Jun-Jul to Oct-Nov (*P* < 0.05, Bonferroni Pairwise Comparisons) (Fig. 1). Their populations returned to the Jun-Jul sizes by Feb-Mar (*P* > 0.05, Bonferroni Pairwise Comparisons).

The mean roosting abundances at LG were statistically similar during Apr-May (194 ± 46 s.e. birds) and Jun-Jul (234 ± 34 s.e. birds) (*P* = 1.00, Bonferroni Pairwise Comparisons). From August onwards abundances continued to increase reaching an overall high of 791 ± 57 s.e. birds during Dec-Jan. Population size fell to 510 ± 52 s.e. birds in Feb-Mar, although this was not significantly different to that from Dec-Jan (*P* = 0.41, Bonferroni Pairwise Comparisons). The mean population size at LG dropped by 507 birds from January (886 ± 44 s.e.) to March (379 ± 53 s.e.).

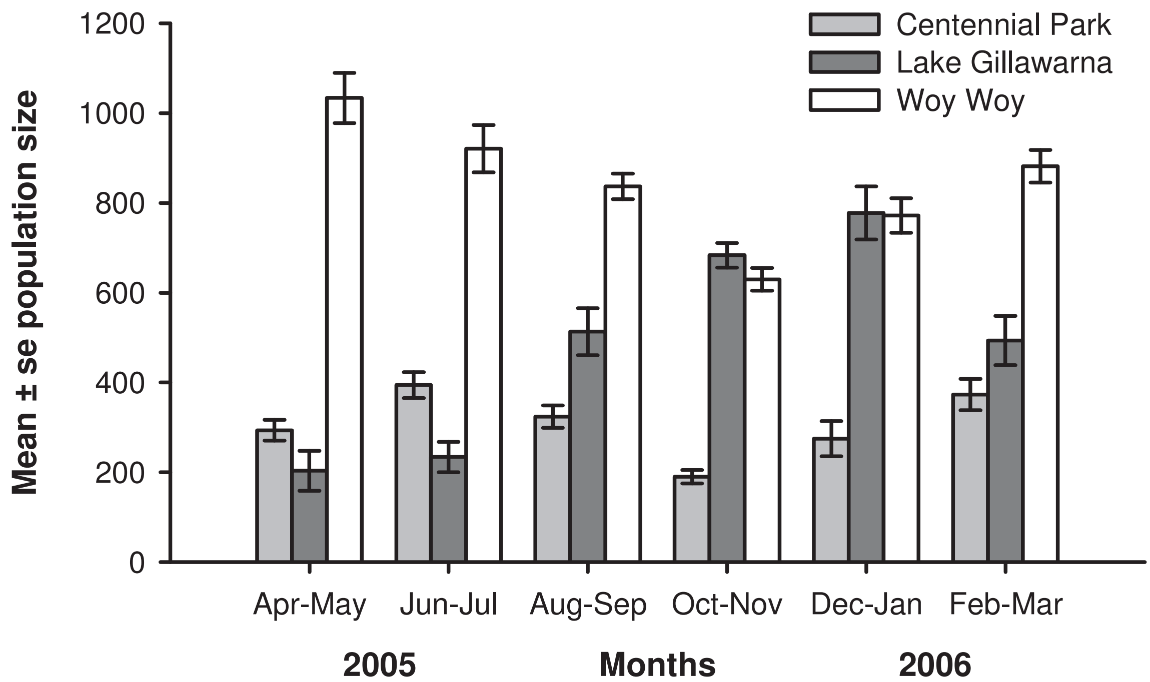
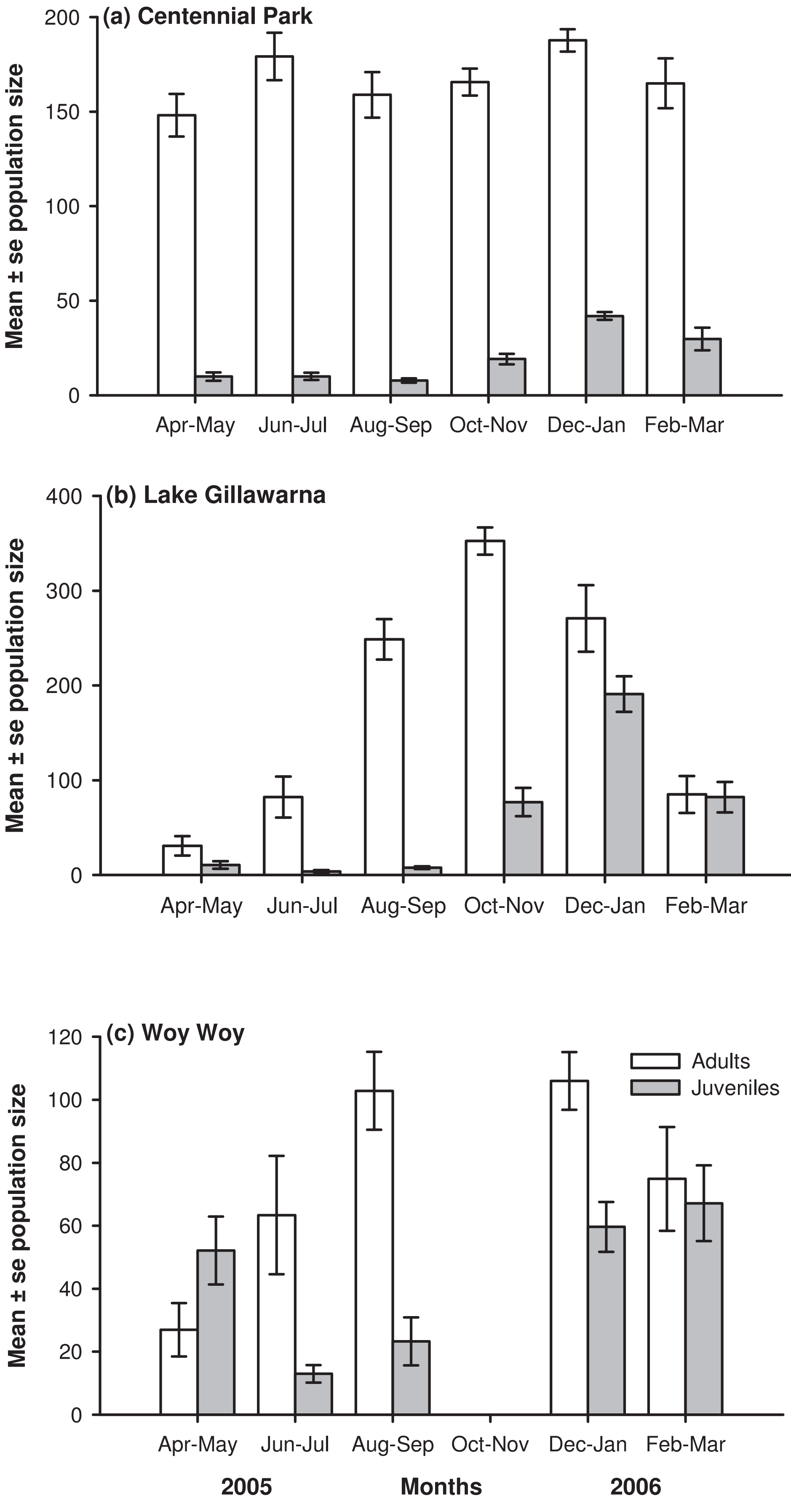


Fig. 1. Mean (± s.e.) roosting population sizes of the Australian White Ibis at Centennial Park, Lake Gillawarna and Woy Woy for six two-monthly intervals from April 2005 to March 2006.

Age composition

Juvenile ibis were present at each site during each two-monthly interval (Fig. 2), but their numbers changed significantly over time at all sites (CP: $F_{5,3}$ = 31.90, LG: $F_{5,3}$ = 103.36, and WW: $F_{4,4}$ = 37.19, P < 0.01 for all comparisons; repeated measures ANOVA). Age compositions at CP and LG (Fig. 2 *a* and *b*) followed a similar trend, with numbers of juveniles increasing from Oct-Nov to Dec-Jan and then decreasing in Feb-Mar. CP had a lower number of juveniles (range: 3 to 40 individuals) year round in comparison to both LG and WW (range: 0 to 288). The juvenile population of WW was lowest from Jun-Jul to Aug-Sep, and highest between December and May. Numbers from December to March were statistically similar to those during Apr-May (P = 1.00, Bonferroni Pairwise Comparisons). No juvenile and adult abundance data were available for Oct-Nov (see text in legend about total population counts). In our last count (late March) only 28 juveniles were sighted at WW, after a peak of 118 birds during mid February.



(a) Centennial Park
Mean ± se population size
200
150
100
50
0
Apr-May
Jun-Jul
Aug-Sep
Oct-Nov
Dec-Jan
Feb-Mar
(b) Lake Gillawarna
Mean ± se population size
400
300
200
100
0
Apr-May
Jun-Jul
Aug-Sep
Oct-Nov
Dec-Jan
Feb-Mar
(c) Woy Woy
Mean ± se population size
120
100
80
60
40
20
0
Adults
Juveniles
Apr-May
Jun-Jul
Aug-Sep
Oct-Nov
Dec-Jan
Feb-Mar
2005
Months
2006

Fig. 2. Mean (± s.e.) adult and juvenile population sizes of the Australian White Ibis at (a) Centennial Park, (b) Lake Gillawarna and (c) Woy Woy for six two-monthly intervals from April 2005 to March 2006. No age composition is available for Woy Woy during October and November 2005 (total population for this period: 126 birds ± 8 s.e.). Note differences in the y-axis scale between graphs.

Fly-in preference

Fly-in directions into roosts were not random ($P < 0.05$, Rayleigh test) and differed between the Sydney (LG and CP) and WW site (Fig. 3). At CP birds arrived mainly from the south-west (52% ± 13 s.d., $\alpha = 228°$, $r = 0.68$, $v = 0.32$, $P < 0.01$; Rayleigh test). This was also the case for LG (36% ± 4 s.d.), where also west (22% ± 3 s.d.) and north-west (16% ± 2 s.d.) directions were prominent. The proportion of birds arriving from the south-west was significantly higher than the proportion of birds arriving from the north-west ($P < 0.01$), but not west ($P = 1.00$). At WW, there was no significant difference between the proportion of ibis arriving from the west (50% ± 4 s.d.) and north-east (35% ± 3 s.d.) ($P = 1.00$, repeated measures ANOVA (Wilk's Lambda)).

Discussion

Roosting population

Ibis used all sites continuously for roosting throughout the year, which suggests that at least some birds in the urban environment are sedentary. While this has been already proposed by Corben and Munro (2008), their study, which was based on a single site and extended only over half a year, did not demonstrate that ibis can be sedentary year round on a broad spatial scale in the urban environment. The result from this study highlight that ibis have developed sedentary populations, which are permanently present in the urban coastal region.

Population sizes differed and fluctuated significantly between sites and over time. So no common pattern existed for all colonies. This needs to be considered when developing

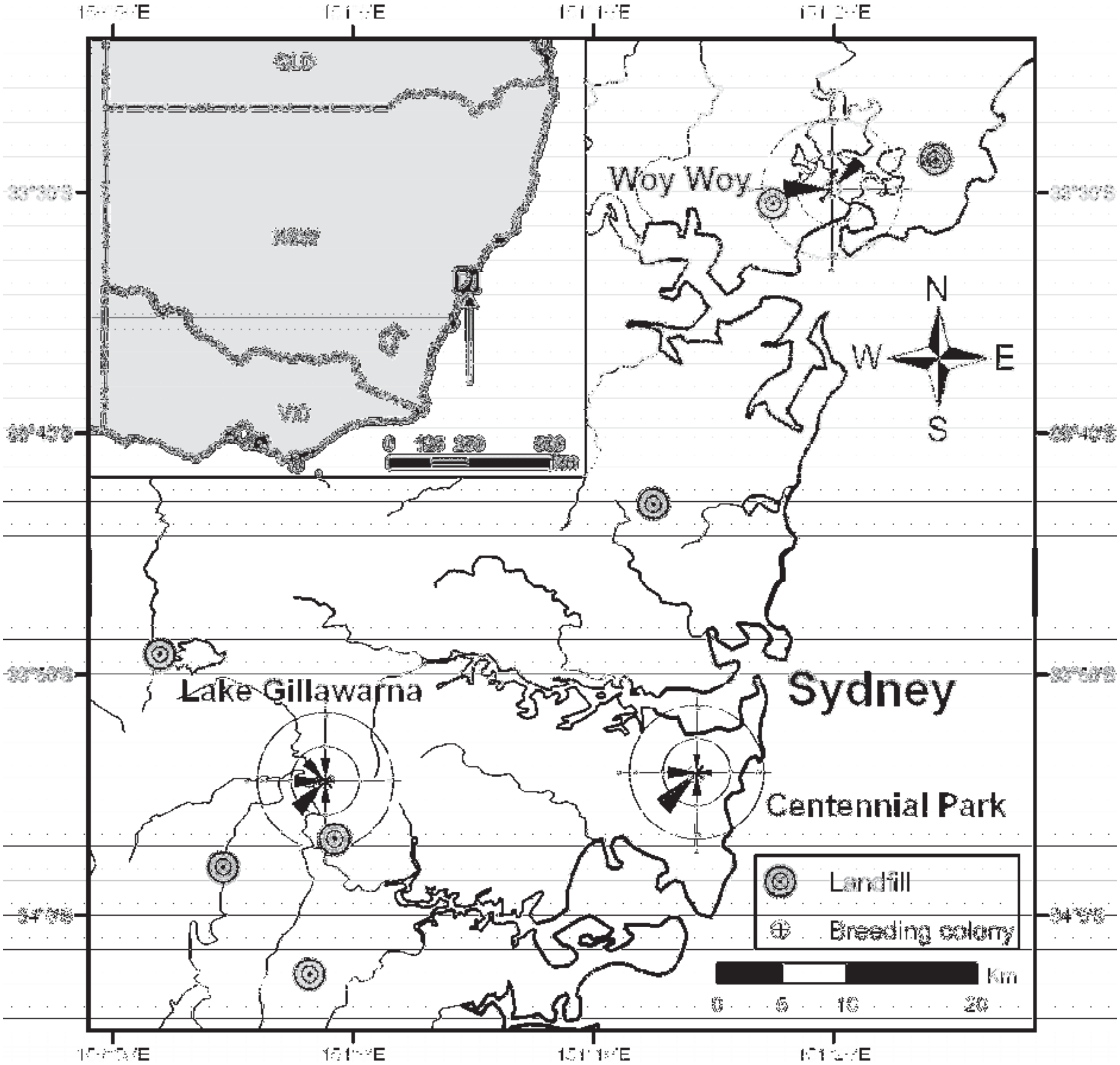


Fig. 3. Fly-in preferences of the Australian White Ibis into their roosts/breeding colonies (= centre of circle) at Centennial Park, Lake Gillawarna and Woy Woy between April 2005 to March 2006. The black wedges in the rose diagram represent the mean percentages (outer circle = 100%, inner circle 25%) of the total number of ibis arriving from each direction. The white arrow in the rose diagram for Centennial Park represents the mean south-western fly-in angle and its vector. Rivers are indicated by thin black lines. The Georges River system is in the bottom left corner and runs directly past LG. Targets symbols (circles with alternating black and white inner circles) indicate the locations of major landfills for household waste.

management plans for ibis, and possibly other colonial breeders, and highlights the need for broad-scale assessments of ibis populations to understand their behaviour in urban environments. A common practice in wildlife management is to study a small subset (e.g. one colony) of a population and derive from it baselines for the overall management of a population or species (Recher *et al.* 1986). In the case of ibis, this could result in inappropriate management plans.

Colonies appear to follow either one of two distinct trends: (1) the population size increases from the onset of the breeding period (Aug-Oct) and crashes after the breeding period (Feb-Mar) (LG), or (2) the population size dips in the middle of the breeding period (Oct-Nov) (CP and WW). Corben and Munro (2008) also studied ibis abundance at CP during the first half of 2003 and found similar trends to those at LG, i.e. increasing population sizes as breeding progressed. This led the authors to propose that ibis colonies undergo seasonal fluctuations, which are caused by a mobile subpopulation that moves from inland Australia into coastal urban sites for breeding (Corben and Munro 2008). A large-scale survey by Thomas (2007) supports this view and has shown that ibis numbers increase at the coast, while they simultaneously decrease in inland eastern Australia from the non-breeding to breeding period. While our results at LG suggest similar, those at CP and WW, do not coincide with Corben and Munro’s (2008) findings. There are several possibilities why this may be so. The colony at CP and several other colonies in Sydney were heavily managed over the 2005/2006 breeding period, and large numbers of nests, eggs and chicks were destroyed (DEC 2005). Many ibis were forced to abandon these sites and consequently could have moved to LG, where no management was performed. Ibis (G. Ross pers. comm.) as well as many other birds (Hepp and Kennamer 1992; Lindberg and Dedinger 1996; Bried and Jouventin 1999; Hoover 2003) are known to move to alternative sites when disturbed while breeding. So the population increase at LG may have been at least partly due to local movements.

While the above seems plausible, it does not explain the decrease in population size in the middle of the breeding period (Oct-Nov) at WW, another unmanaged site, and CP. A common feature of both may be limited space for breeding and roosting. The colony at WW is situated on a small sandbank, which restricts nesting and roosting. At CP, where in the past large numbers of ibis bred (Corben 2003), park managers conducted a major restoration program and reduced vegetation suitable for ibis nesting and roosting dramatically (Corben 2003). As a consequence competition for roosting and breeding space may have increased. From Sep-Nov young ibis from the first clutches fledge and become independent. Since they are inferior in competing for roosting spaces (Beilharz 1988), they may have been forced to abandon their hatching sites, which may in turn have caused the decline in population size at these sites. At the LG colony on the other hand, where far more nesting and roosting sites were available, immediate departure of fledging ibis was not necessary.

The main conclusion we can draw from our study is that ibis colonies differ. It is difficult to state yet, why this is the case and what factors influence the behaviour of a colony. At present, we know too little about these colonies. While we have focused in our study on three large colonies, which currently are continuously occupied, many smaller and/or non-permanently occupied colonies (e.g. Cabramatta Creek) exist. Since such non-permanent colonies can develop into permanent colonies (pers. obs.), it is possible that they represent only recently occupied sites. It is not known how non-permanent colonies become permanent. The increased sedentary lifestyle of ibis possibly in conjunction with predictable food resources (e.g. landfills) (Ross 2004) appears a likely cause. Sydney also hosts many small colonies (<20 birds) during the breeding period. Most colonies occur, like the larger urban (pers. obs.) and natural colonies, near water (often on islands) with nests typically erected on vegetation (Cowling and Lowe 1981). Some colonies (e.g. Parramatta, Redfern and Ultimo) have recently begun to deviate from this and ibis nest on vegetation not surrounded by water. Reasons for this behavioural change are not known, but may be related to current management and overall shortages of nesting places in Sydney. Since 2003 some large colonies (e.g. CP, Cabramatta Creek) have suffered from heavy management (Martin *et al.* 2007), which may have forced their breeding populations to search for alternatives.

Similar has been reported for gulls in Europe, where attempts to restrict their breeding resulted in fragmented populations (Clergeau 2005). Since breeding sites in the city are limited, the ibis may have simply reverted to sites, which host their preferred breeding trees (e.g. Phoenix Palms (*Phoenix dactylifera*), Coral Trees (*Erythrina* x *sykesii*), She Oakes (*Casuarina glauca*)), but are not necessarily surrounded by water. The possibility of fragmenting populations through management needs to be considered, when a reduction in breeding success is attempted. Egg oiling is one management practise that could lead to colony fragmentation (see Martin *et al*. 2007).

Age composition

In general there was a significant increase in the number of juveniles towards the end and start of the year for each site (Fig. 2a-c). These increases are a direct result of breeding, which begins in early June, peaking between August and November, and can last until late March (Marchant and Higgins 1990; Corben and Munro 2008). LG had the most juveniles (peaking at 288) compared to the other sites, while CP had the least (peaking at 40). Since the number of juveniles can act as a surrogate measure of the breeding success of a colony (Minton 2003), LG appears to be the best site for breeding. It is interesting that the reproductive success was considerably higher at LG than at WW, where the overall population was often larger than at LG (see Fig. 1). This means that population size is not necessarily an indicator for reproductive success. This needs to be taken into account when managing large colonies, and highlights that reproductive success needs to be assessed before extensive cost and labour intensive measures (DEC 2005) are employed for reducing breeding success.

It appears that many juveniles leave their colonies soon after fledging with only a few remaining in late March. This coincides with previous findings at WW (Thomas 2007). It is uncertain where the juveniles go. Banding results (unpub. data) suggest that many of them travel to Sydney's landfills or depart from the area altogether moving as far up as Queensland (see chapter 6). Juvenile ibis are known to travel very long distances (>3500 km) from their hatching site (Carrick 1962; Purchase 1975), thus the breeding colonies in Sydney and other urban areas could provide recruits to populations from other regions. Management that limits fledging success of urban ibis could potentially affect recruitment on a regional scale.

Fly-in preference

Fly-in preferences to roosts were consistent for each site, which suggests foraging site fidelity. This has also been proposed by Murray (2005), and Corben and Munro (2008). The mean south-western fly-in direction at CP corresponds to that observed by Corben and Munro (2008) previously (Fig. 3). The authors speculated that ibis from CP foraged mainly at Lucas Heights landfill (~35 km SW of CP). Recent colour-banding studies support this view (unpubl. data). However, CP birds were also sighted at other landfills for household waste (e.g. Belrose (~20 km N of CP) and Eastern Creek landfill (~45 km W of CP) (unpubl. data)). Thus, the foraging range of ibis is probably larger than previously thought.

Fly-in preferences at LG were orientated towards SW, W and NW, with almost no birds arriving from the east. The fly-in directions were generally aligned along the Georges River and its tributaries (a large river system adjacent to LG), which suggests the birds used this system as a directional guide to travel between their roost and foraging areas. This may also explain the wider spread of arrival directions at LG rendering it harder to pinpoint their foraging areas. The Kelso (~2 km S), Eastern Creek (~15 km NW) and Lucas Heights landfills (~15 km S) are potential sites, since they lie within the foraging ranges of ibis (~25 km, see Murray 2005) and colour-banded ibis from LG have been sighted at the Eastern Creek and Lucas Heights landfills (unpubl. data).

WW with its distinct western and north-eastern fly-in directions leaves little doubt that the birds are foraging at the Woy Woy (~5 km W) and Kincumber landfills (~7 km NE), which supports the view that this colony is predominantly sustained by landfills (see Thomas 2007). Should access to these landfills ever be restricted to the birds, this colony is likely to shrink or disappear altogether.

Conclusion

The main conclusion we can draw from our study is that ibis colonies differ in their seasonal abundance and age composition. We do not know why this is the case, until further investigations focusing on the age, size, and effects of environmental factors and management of colonies are available. We recommend that future studies focus on small and/or non-permanent colonies, the likely founders of large, permanent colonies, so that processes for the establishment and development of large colonies are identified. Since ibis have recently developed small colonies in urban environments away from large water bodies (which complicates management), research should also focus on identifying the reasons (e.g. current management practices (Martin *et al.* 2007)) for this behavioural change.

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Chapter 5.

Local and regional movements of the Australian White Ibis (*Threskiornis molucca*).

Abstract Little is known about the movements of Australian birds. Information is particularly scarce on large, aquatic birds, which are usually difficult to access and handle. Their movements are also often complex, and require substantial datasets collected over many years to unravel details. Here we present data on the local (Sydney-wide) and regional (Australia-wide) movements of the Australian white ibis (*Threskiornis molucca*), a highly mobile bird, whose movements are currently little understood, but need to be known, so that appropriate management plans can be developed to combat its abundance in urban environments. Our analysis of past and present banding studies revealed that ibis travel throughout the urban environment and often visit landfills. On a regional scale north to north-east-ward movements dominate, which lead birds from their breeding sites most likely along the east coast from south-eastern Australia to regions further north (Queensland and Papua New Guinea). Young birds return to their hatching site, but only after they have reached sexual maturity. Their preferences for landfills, high mobility, complex movements and current decline in inland Australia need to be considered, when developing and implementing management strategies.

Keywords Australian white ibis · *Threskiornis molucca* · Movement · Urban ecology · Landfill

Introduction

In contrast to the extensive knowledge on the movements of Northern Hemisphere birds (e.g. Alerstam 1990) little is known about their Southern Hemisphere counterparts (Griffioen and Clarke 2002). In Australia, for example, where a large proportion of birds is mobile (Chan 2001; Griffioen and Clarke 2002), only the migrations of several east coast intra-continental passerines (e.g. Munro et al. 1993, Munro 2003; Funnell and Munro 2007) and some shore- and seabirds (Waterman et al. 2003; Minton et al. 2006; Geering et al. 2007) have been described in some detail, while the movements of birds from other taxa are often poorly understood (Kingsford and Norman 2002). This is especially the case for large and/or aquatic birds (Carrick 1962; Norman 1970; McKilligan 1975; Geering et al. 1998; Roshier et al. 2008), which are often difficult to access and handle. Their movements can also be far more complex (Kingsford and Norman 2002) than those of many migratory passerines, which usually follow distinct annual routes (Mead 1983; Berthold 2001). Consequently, the movements of these birds are difficult to identify and often require sophisticated methods (Papi et al. 1997; Jiguet and Villarubias 2004) and/or long-term large-scale efforts to obtain appropriate datasets (Carrick 1962).

The Australian white ibis (*Threskiornis molucca*) (hereafter referred to as ibis, if not stated otherwise) is one such species, whose movements appear complex. Current literature suggest that this bird (a) is sedentary as well as mobile (Corben 2003, Corben and Munro 2008), (b) travels long distances northwards as far as New Guinea (Carrick 1962, Purchase 1976), (c) performs eastwards movements from the Australian inland towards the coast (Thomas 2007), and (d) conducts movements, which may differ between first year and adult birds on a temporal scale (Thomas 2007). Further evidence suggests that they also travel on a local scale between their roosts and landfills to forage (Murray 2005). Unfortunately, some of these studies are based on small sample sizes (Carrick 1962; Murray 2005), and/or cover only short time scales (Corben and Munro 2008), which limit general conclusions on the movements of ibis.

With the recent dramatic increase of ibis in urban environments (Murray and Shaw 2006; Corben and Munro 2008), understanding their movements has gained importance. The ibis began to invade the Australian east coast approximately 30 years ago (Morris 1983; Ross 2004) and today occurs in large numbers in many coastal cities (e.g. Sydney, Melbourne, Gold Coast) (Corben and Munro 2008; Ecosure 2009). The public and many agencies with ibis problems often demand a rigorous reduction in their numbers (Martin et al. 2007). While such measures seem appropriate for other ibis species, which have become exotic invaders (e.g. sacred ibis (*T. aethiopicus*) in Europe (Yésou and Clergeau 2005; Clergeau and Yésou 2006a) and Florida, USA (Herring and Gawlik 2008)), this may not be justified for Australia's native white ibis (Marchant and Higgins 1990). This species has extended its breeding range into eastern coastal and urban environments since the 1970's (Bekle 1982; Morris 1983; Ross 2004), probably due to water shortages caused by drought and irrigation (Corben and Munro 2006, 2008) in its traditional inland wetland breeding areas (Carrick 1962; Cowling and Lowe 1981), where it is currently in decline (Porter et al. 2006). While its expansion has many ecological, social and economic consequences (Mack et al. 2000; Corben 2003; Ross 2004), which require management, a rigorous reduction in numbers may affect the species on a local as well as a regional scale (see Corben and Munro 2006, 2008; Thomas 2007). Since we know only a little about the species' movement, it is difficult to determine any effect management would have on the population as a whole, or the proportion of a population that can be safely removed without harming the long-term survival of the species.

In the current study, we provide a comprehensive overview on the local and regional movements of ibis and provide results from past (records of the Australian Bird and Bat Banding Scheme (ABBBS), Environment Australia, Canberra) and present banding studies with the aim to establish: (a) whether the ibis colonies in the urban environment (Sydney) represent separate populations or are interlinked, (b) whether ibis travel to landfills for foraging, and (c) how far they travel within the urban environment and on a regional scale. These results represent a solid baseline for future management plans for the Australian white ibis, and potentially the closely related sacred ibis, a recent exotic invader in Europe (Yésou and Clergeau 2005; Clergeau and Yésou 2006a), the United States of America (Herring and Gawlik 2008), and possibly south-east Asia (Clergeau pers. comm.).

Methods

Study animal

The Australian white ibis is endemic to Australia, the southern areas of Papua New Guinea and some of the surrounding islands (Marchant and Higgins 1990). It is closely related to the sacred ibis from Africa, and both were until recently regarded as the same species (Lowe 1984; Lowe and Richards 1991). The Australian white ibis roosts and nests colonially near water bodies and on small islands (Ross 2004). Traditionally nesting occurred in the inland wetlands system (e.g. Murray-Darling river system (Carrick 1962)), but today also takes place in many coastal environments of eastern Australia (Corben and Munro 2008). In their natural inland habitat breeding events are correlated with sufficient water flows into wetlands (Kingsford and Johnson 1998; Kingsford and Auld 2005). Once ibis fledge they can travel long distances, and some banding recoveries suggest movements to southern Papua New Guinea, >3500 km from the banding site (Carrick 1962; Purchase 1976). Today ibis are common within urban parks and landfills in Australia, which they use as feeding sites (Ross 2004).

Study sites

We studied the Australian white ibis from three urban colonies in the wider Sydney area (New South Wales, Australia) between April 2005 and April 2006. The colonies were located at: (a) Centennial Park (CP) (33°32'S, 151°8'E), an urban park (360 ha) in eastern Sydney; (b) Lake Gillawarna (LG), Bankstown (33°32'S, 150°35'E), an artificial wetland in western Sydney; and (c) a sand island near Pelican Island in the Hawkesbury River estuary within Brisbane Waters, near the town of Woy Woy (WW) (32°30'S, 151°20'E, ~80 km NNE of Sydney's centre). All colonies were confined to small islands (CP: 0.04 ha; LG (two islands): 0.45 and 0.03 ha; WW: 0.10 - 0.50 ha (depending on tidal levels)), which were always surrounded by water throughout the entire breeding period. All sites were close (less than 25 km) to landfills (depositories for domestic waste), where ibis regularly forage (personal observation). The island at WW also hosted a large breeding colony of approximately 500 Australian pelicans (*Pelecanus conspicillatus*).

Data collection

Local movements

To determine local movements of ibis (= movements above 5 km and within a 100 km radius of central Sydney), 830 birds were banded on their right tarsus using numbered bands from the Australian Bird and Bat Banding Scheme (ABBBS, Environment Australia) between 25 May 2005 and 5 April 2006. All birds were banded as pulli (CP: 14; LG: 322; and WW: 456 birds), except 38 birds from CP, which were banded as older juveniles or adults. 689 of all number banded birds were also fitted with a colour band on their right tibia, which indicated the banding location (e.g. red = CP; white = LG; purple = WW). 306 of these birds also wore two additional bands on their left tarsus, which, together with the location band, enabled us to individually identify birds in the field.

Recoveries and re-sights of birds banded during our current and previous small scale banding studies in the wider Sydney area (i.e. Kingsford Smith Airport (33º34'S, 151º6'E) and the Royal Botanical Gardens (33º52'S, 151º13'E) between 2002-2004) were obtained through weekly surveys of all our banding sites between April 2005 and April 2006, and Sydney's three major landfills for household waste (Eastern Creek (33º48'S, 150º51'E), Belrose (33°43'S, 151°13'E) and Lucas Heights (34º2'S, 150º58'E)) between September 2005 and January 2006 (records of D. Mulquin, University of Technology, Sydney (UTS)). Additional records were obtained from the general public, the ABBBS (Australian Bird and Bat Banding Scheme) database (>10 000 birds banded between 1955 and 2007, resulting in 789 overall recoveries), and further weekly surveys at LG and CP between 15 August and 15 October 2006, LG and WW between 3 March and 10 August 2007, and WW on 31 December 2007 and between 6 May and 24 June 2008 (records of V. Kubur, J. Roberts and C. Thomas, UTS). All local movements were mapped using ArcGIS (version 9.3) (see Fig. 1).

Regional movements

To determine regional movements, we combined our four long distance band recoveries (≥300 km) with all the current long distance band recoveries for ibis reported in the literature (Carrick 1962; Purchase 1975) and in the ABBBS database (1955-2007). All recoveries were from birds, which had been banded as nestlings or recent fledglings. All long distance recoveries (n = 64) were mapped using ArcGIS (Version 9.3) (see Fig. 2). The map template was obtained from Geoscience Australia (2009). One band recovery from Western Australia was omitted as it represented the only recovery from this part of Australia. In order to obtain a rough estimate of how fast ibis can travel on a regional scale, we screened our dataset for birds, which had covered large distances (above 500 km) in short times (less than four months). The average travelling speed of these birds was calculated by dividing the distance the birds had covered by the days the birds needed to travel this distance.

Breeding site fidelity and sexual maturity

In order to determine when ibis reach sexual maturity and whether they return to their hatching site, we screened our data set for recoveries of birds we had banded during the 2005/2006 breeding period and resighted at the same site at a later stage. The time difference between the banding and recovery date was used to estimate the duration ibis required to become sexually mature.

Results

Local movements

In total we re-sighted 143 banded ibis and identified 26 pathways, between roosting sites and Sydney's major landfills (Fig. 1). Strong movements (≥five re-sighting of different birds) occurred between the two study sites (breeding colonies) (Centennial Park and Lake Gillawarna) and the three major landfills (Belrose, Eastern Creek and Lucas Heights) within Sydney. Banded ibis from CP, LG and WW were also discovered at other roosting/breeding sites and travelled between landfills (e.g. Belrose, Eastern Creek and Lucas Heights). 90% of all local re-sightings occurred at these landfills, despite extensive surveys of roosting sites. Four individually colour banded birds visited at least two landfills, with one bird from CP visiting the Eastern Creek, Belrose and Lucas Heights landfill within three months. Two juveniles covered the longest distance by travelling from WW to the Lucas Heights landfill (~ 60 km SSW of WW).

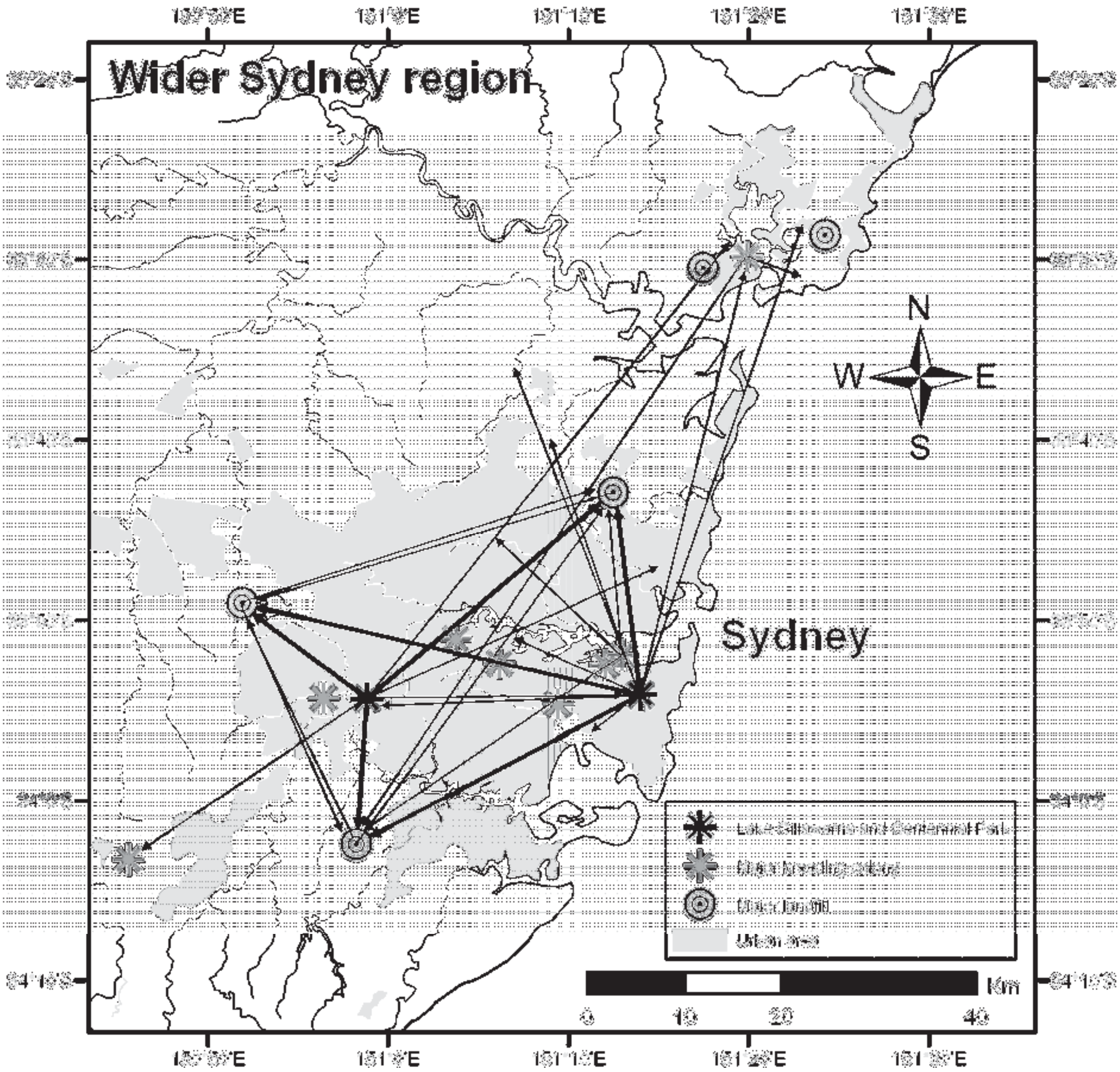

Fig. 1. Local movements (≤100 km radius from Sydney's centre) of ibis (n = 26 flight paths). Sites that were visited by ibis are connected by lines with the arrow heads indicating the re-sighting locations. Thin lines (n = 20) represent the movement of one ibis between sites; thick lines (n = 6) indicate the movement of at least five different ibis moved between the sites. The landfills in the bottom of the graph (Sydney area) are Belrose (top), Eastern Creek (middle) and Lucas Heights (bottom). The landfills at he top of the graph are Woy Woy (left) and Kincumber (right), which are in the immediate vicinity of the Woy Woy ibis breeding colony. The breeding colony at LG (left) and CP (right) are indicated by a black asterisk, all other major breeding colonies (≥ 100 nests: 2005 to 2007) in the wider Sydney region are represented by grey asterices.

Regional movements

64 recoveries (from 1955 to 2007) extended over long distances (>300 km) (Fig. 2). When mapping these recoveries, north to northeastward movements dominated (Fig. 2), which suggest that birds from Victoria direct their movements towards Sydney, the Gold Coast/Brisbane region and northern Queensland (Cape York) and southern Papua New Guinea. Two long distance recoveries (from Brisbane (27º41'S, 153º4'E) to southern Victoria (37º54'S, 144º40'E and 38º19'S, 144º43'E) (travel distance: 1,380 and 1,415 km) point southward (219° and 218°) and suggest that return movements take place. 80% of all resights (n = 52) were within 100 km from the coast line.

Ibis can cover large distances in short times. One bird was recovered at Nanango, Queensland (26°40'S, 152°0'E), on 14 April 1961 87 days after it had been banded (by P.A. Disher) as a nestling at Kow Swamp, Victoria (35º56'S, 144º18'E) on 17 January 1961. Assuming that the bird left on the day of banding and arrived on the date it was recovered, this bird had travelled at least 1,262 km with an average travel speed of 14.51 km/day. Another bird, banded as a nestling at LG on 6 January 2004, was recovered at Currumbin, Queensland (28º12'S, 153º24'E) on 22 April 2004, exactly 107 days later. Here the bird had flown a total distance of at least 675 km in 107 days at an average speed of 6.31 km/day. Since both birds were banded as nestlings and may not have fledged until two to three weeks after banding, the birds had probably covered these distances in a far shorter time.

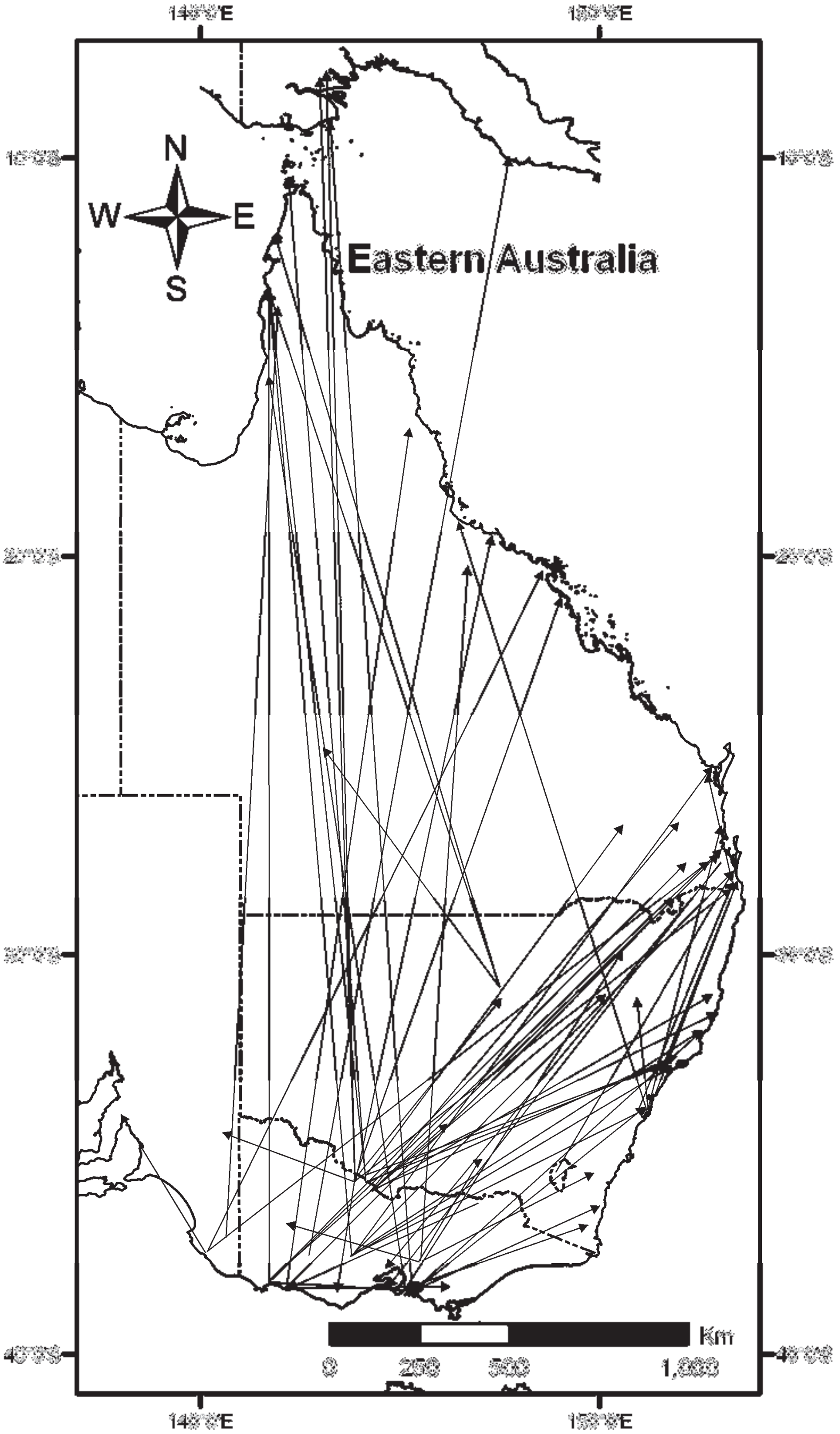

Fig. 2. Regional movements (≥300 km) of ibis (n = 65) in eastern Australia. All lines originate at the banding places of ibis and end with an arrow head at the recovery sites of the birds. Four birds were recovered in Southern Papua New Guinea.

Breeding site fidelity and sexual maturity

Three birds, which were banded as nestlings at WW during the 2005/2006 breeding period, were resighted at WW during the 2007/2008 breeding period. Bird 121-51556 (yellow/green-purple/metal, banded: 30 August 2005) and a bird with an unknown number band and a purple location band (fitted between 6 and 20 September 2005) were resighted on 31 December 2007 (27.5 and 28 months later). Another bird (121-51578; purple location band, banded: 6 September 2005) was recovered on 8 July 2008 (34 months later). It is possible that this bird was identical to the second bird with the unknown number band sighted on 31 December 2007. All three birds were in adult breeding plumage and attended nests or were caring for young. No ibis banded as a pullus during the 2005/2006 breeding season was resighted during the 2006/2007 breeding period, despite extensive monitoring (records of V. Kubur and C. Thomas, UTS).

Discussion

Our findings confirm that the ibis is a highly mobile bird on a local and a regional scale. Band recoveries revealed that birds travel between roosting sites and colonies are interlinked. They also frequently fly from their roosts to landfills, where ibis forage in large numbers (Thomas 2007; pers. obs.). It is interesting that birds do not only visit the landfill closest to their roosts, but travel long distances to reach landfills further away from their colonies. We do not know why ibis travel such long distances, when a landfill is close by. Several reasons are possible. During the breeding season the number of ibis and pelicans (another frequent visitor of Sydney's landfills) is high and simply may not provide sufficient food for all scavengers, so some birds are forced to search and explore other sites. Differences in food quality and quantity at landfills may be another reason, or the birds have come across these sites, while exploring their home range. The use of multiple landfills has major implications for managing these birds. Since ibis use more than one site for foraging, or at least are able to do so, it may make little sense to focus just on a single landfill, when attempting to manage these birds. Preventing ibis to scavenge from one site may simply shift the problem to another site. Instead all landfills in an area should be incorporated, should management be desired.

The regional recoveries of ibis (Fig. 2) highlight the vast distances these birds can cover. The band recoveries confirm previous reports (e.g. Carrick 1962; Purchase 1976) of north and northeast-ward movements of ibis from south-eastern Australia (mainly Victoria and New South Wales) into Queensland and up to Papua New Guinea. Since banding studies usually only provide us with the location, where the birds have been originally banded, and the end point of their travels, it is difficult, in particular when long distances are involved, to conclude about the exact route the birds are taking. The high recovery rates from birds banded in Victoria along the lower south-eastern coast of New South Wales and southern Queensland (mainly within 100 km from the coast) suggests that movements generally follow the eastern coastline, which could also act as a landmark during their travels, as in other large day migrating birds (Geyr von Schweppenburg 1929). It is obvious that at least some birds travel beyond southern Queensland up to northern Queensland and as far up as Papua New Guinea (Carrick 1962; Purchase 1976; see also Draffan et al. 1983), but which route these birds take is difficult to reconstruct. Only a few birds have yet been banded in southern Queensland, and none of them (with maybe one exception) have been recovered further north. So the possibility that ibis travel directly from Victoria to northern Queensland, cannot be excluded entirely, in particular since we know from our analysis that ibis can cover, like the closely related sacred ibis (Dowsett 1969), considerable distances in short times (e.g. 1,262 km in 87 days). Nevertheless, we consider this unlikely, because resting and feeding stops for aquatic birds can be limited in the vast semi-arid outback of inland

Australia, and despite the fact that the birds need to travel further, a coastal route offers more reliable resources.

Since banding programs on ibis have mainly focused on birds, which were banded in Victoria and New South Wales (mainly Sydney), with no equivalent programs at locations further north, our data provide us with strong evidence for northward movements, but with less conclusive evidence of return movements. Two long distance recoveries from birds banded in Brisbane (southern Queensland) in Werribee and Portsea Beach, Victoria, suggest that at least some birds travel south. It is not clear whether this is an annual event for each bird, and is strictly followed by each first year and adult birds. Since the ibis belongs to the Ciconiiformes, which mature late (Hancock et al. 1992) and can show differential migration (Berthold 2001), we regard this as unlikely. Instead we believe that the movements of the adult and young may differ, which finds some indirect support in previous research. Both Thomas (2007), and Corben and Munro (2008) reported that fledgling ibis disappear from their breeding areas and only adult birds remain. At the start of the next breeding period, the colonies consist nearly entirely of adults, whose numbers increase as breeding progresses, with either no or very few young present (Corben 2003). The above in conjunction with our banding results suggest that the young birds travel widely, but do not return to their hatching site until they have reached sexual maturity. Similar (i.e. a retarded or graded return to the breeding site; see Berthold 2001), is known from the white stork (*Ciconia ciconia*), the osprey (*Pandion haliaetus*), herons and some waders. In these species the young leave the breeding sites, and remain at their non-breeding resting places beyond their first year of life, or they travel only a fraction of their return path back to their breeding site, and spend the time until sexually mature as a ´non-breeder´ at a suitable site (Berthold 2001). During their absence young storks can, conduct large-scale movements, which appear to differ in their scale, route and goal to those of adults (Berthold 2001). While we cannot be certain that this also applies to ibis, a study by Thomas (2007), who describes large-scale movements of ibis (presumably mainly adults) from inland Australia coastward for breeding, also indicates that adults may, at least to some extent, incorporate other routes into their overall movements.

Until our study, it was not known, when ibis reach maturity. While the closely related sacred ibis acquires its adult plumage at three years of age, it is uncertain whether it commences breeding at this stage or delays it until a later age (Hancock et al. 1992). Based on our resights of banded birds at WW, we know now that ibis obtain their adult plumage, and can commence breeding and care for chicks, when two-years old. These results are important for several reasons. They provide clear evidence when ibis reach sexual maturity, show that ibis can successfully breed at a young age, and exhibit site fidelity to their hatching site, all of which is important for the development of management plans for this bird. The return of the young birds to their breeding site is of particular interest. It suggests these young birds have a bond to their hatching site and can commence breeding, where they have been raised successfully. Therefore it is likely that at least some ibis will continue to exist in urban environments, and will not return to their inland wetlands, in case water flows are restored.

Besides being highly mobile, ibis appear to be also sedentary, which seems to be especially prevalent in coastal urban environments (Corben 2003, Corben and Munro 2008). As yet it is not known what causes some birds to remain behind. Several explanations appear possible. Firstly, resource availability is high enough, which allows a part of the population to stay on the breeding ground, which is common in many birds with flexible movement patterns (Berthold 2001; Funnell 2007). Resources are often particularly high in urban environments (Cooke et al. 2006), and there are numerous accounts in the literature that show that migratory birds from densely populated areas cease to migrate and adopt a more sedentary lifestyle (Partecke and Gwinner 2007), or shorten their migration routes in response to abundant food resources (Blanco 1996; Barbraud 1999; Tortosa et al. 2002, 2003). This could also apply to the ibis, and would suggest that the now sedentary population has split from the mobile population. In this process some birds may have not become completely sedentary, but instead shortened their migration routes. This may explain the high abundances in Australia's east coast cities, (e.g. Sydney and Brisbane), which all lie along the general northward route birds from further south would take, and the far fewer numbers in Adelaide, South Australia (Barrett et al. 2003), which lies outside their main path. Secondly, the ibis that remain behind are distinctly different from the mobile population and originate from escapees (DEC 2005). In 1973, seven pairs of ibis escaped from Taronga Zoo, Sydney (DEC 2005). It has been suggested that these birds underwent a rapid increase, perhaps in a similar fashion as the closely related sacred ibis, a recent zoo escapee in Europe (Yésou and Clergeau 2005; Clergeau and Yésou 2006b), which ultimately resulted in overabundances in our cities (e.g. Corben and Munro 2008). However, in Australia many coastal cities host large ibis populations (e.g. Ecosure 2009), where no zoo escapees have been reported, which could explain the large numbers. While it is possible that some ibis spread from the Sydney population into other urban centres, it appears more likely that current overabundances are due to the shortening of migration routes (see above) and a large, potentially regular influx of ibis from the drought-affected areas of inland Australia (Thomas 2007; Corben and Munro 2008). So while we do not believe that the escapees from Sydney's zoo have caused populations to explode, it is, however, possible that they are the founders of the now sedentary population.

The above leaves us in a difficult situation, which shows many parallels to those of the grey-headed flying-fox (*Pteropus poliocephalus*), another highly mobile species (Eby 1991), which suffers overall declines (Eby and Lunney 2002), while being abundant in Australia's east coast cities (McDonald-Madden et al. 2005; Parris and Hazell 2005; Williams *et al.*

2006). In both cases the species' natural habitat has been destroyed or is severely degraded (Kingsford and Thomas 1995, 2004; Kingsford and Johnson 1998; Eby and Lunney 2002; Kingsford and Auld 2005), forcing them to seek alternatives in our cities (Eby and Lunney 2002; Ross 2004). Since both animals roost in large congregations (Eby and Lunney 2002; Ross 2004), which emphasizes their smell, noise, and vegetation damage they cause (Martin et al. 2007), they are of low aesthetic appeal to the public (Eby and Lunney 2002; Corben and Munro 2006). Both species are native, and legally we need to ensure that they survive. It appears that as long as their natural habitats are not restored to a level, which supports their survival and appropriate recruitment (an unlikely event in view of climate change and further water shortages (Finlayson et al. 2006)), they may continue to decline. This leaves us with the only option to allow their existence, at least to some extent, in our cities. In cases, where management authorities decide that a reduction in numbers is essential, the most effective approach is probably to reduce access to landfills and the food resources they contain.

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Chapter 6.

Food for thought: urban landfills, not a wasteland for some of Sydney's birds.

Abstract. In many parts of the world, birds feed at landfills. Some species do so in such large numbers that they require management. In Australia, little is known about birds that feed at landfills. Here we present data on bird abundances on five landfills for household waste in the wider Sydney (Australia) region. The most abundant birds were the Australian white ibis (*Threskiornis molucca*) (approximately 15-30% of the total population were juveniles) and Australian pelican (*Pelecanus conspicillatus*). Other species at low abundances included the silver gull (*Larus novaehollandiae)* and Australian raven (*Corvus coronoides*). All major ibis breeding colonies were located near these landfills. At one site north of Sydney (Brisbane Waters region), approximately 77% of the total roosting population of ibis visited two local landfills during the day. Studies on the feeding rates of ibis at Sydney's landfills indicate that they swallow on average 1.8 food items per minute. 50-60% of the total population of ibis at landfills were feeding directly on the tip-face (waste depository point).

Introduction

In many parts of the world anthropogenic (household) waste is deposited at landfills (Meyer *et al.* 2003). The high concentration of food waste at these landfills can attract a high diversity and abundance of scavenging wildlife, in particular birds (Adams *et al.* 2006). Detailed studies of wildlife on landfills are rare (Meyer *et al.* 2003), which is probably due to the unpleasant environment landfills pose to humans. Nevertheless, research on wildlife at landfills is urgently needed, since an increasing number of species relies on landfills, and may require management (Meyer *et al.* 2003). Wildlife on landfills can face several problems. For examples, animals can become entangled in waste products (Blanco 1996), diseased (Belant 1997; Epstein *et al.* 2007), poisoned (Millsap *et al.* 2004; Mandel and Bildstein 2007; Elliott *et al.* 2006) and malnourished (Smith and Carlile 1993; Annett and Pierotti 1999).

Relying on landfills for food may also reduce breeding success (Pierotti and Annett 1987; Murphy *et al.* 1984; Belant *et al.* 1998), but can also increase survival and reproductive output (Pons and Migot 1995; Brousseau *et al.* 1996; Tortosa *et al.* 2002; Olea and Baglione 2008).

Generally, there are two types of birds that feed at landfills: (1) rare species that depend on landfills for survival, such as the white stork (*Ciconia ciconia*) in western Europe (Tortosa *et al.* 2002) and the bald eagle (*Haliaeetus leucocephalus*) (Sherrod *et al.* 1976; Jackson 1981; Elliot *et al.* 2006), and (2) overabundant species, such as the silver gull (*Larus novaehollandiae*) (Smith and Carlile 1993) and rook (*Corvus frugilegus*) (Olea and Baglione 2008). As landfills are often located near or within urban areas, a high abundance of birds can cause many problems for humans (Belant 1997). For example, they can (1) accelerate the spread of human diseases (Durrant and Beatson 1981; Monaghan *et al.* 1985; Ortiz and Smith 1994; Belant 1997), (2) increase the risk of collision with aircrafts, when birds fly over airports to reach landfills (Solman 1981; Belant 1997; Burger 2001), and (3) become a general nuisance to the public through their overabundance and nesting in the urban environment (Belant 1997).

Most studies on birds at landfills are from the Northern Hemisphere (Meyer *et al.* 2003), while little is known about their Southern Hemisphere counterparts. In Australia, a highly urbanised country (Hugo and Smailes 1985), approximately 17.5 million tonnes of waste are generated annually (2002-03), 30% been municipal waste (ABS 2006). This waste is deposited mainly at large landfills in urban centres (ABS 2006). These landfills are visited by a variety of animals, in particular birds (J. White (Waste management services, NSW), pers. comm.), but no detailed studies on species diversity and abundance exist for these landfills.

Since Australia's landfills can be very large, with some receiving over half a million tonne of waste per year (J. White (WSN), pers. comm.), some species probably occur in high abundances, and need management. At present, the only species that have been studied at Australia's landfills, are the silver gull (Smith and Carlile 1993), kelp and Pacific gull (*L. dominicanus* and *pacificus*) (Coulson and Coulson 1998; Auman *et al*. 2007) and feral cat (*Felis catus*) (Hutchings 2003).

The aim of this study is to identify the birds that use landfills in the wider Sydney region (a highly urbanised area on Australia's east coast) and provide baselines for further research and management. Specifically, we focused on identifying: (1) the species present at landfills and their abundances, (2) to which extent ibis (most common species) rely on them, and (3) the age composition, feeding rate and presence of ibis on the tip-face (point of waste deposition).

Methods

Study species

The main species studied here are the Australian white ibis (*Threskiornis molucca*) and the Australian pelican (*Pelecanus conspicillatus*), Australia's only species of pelican. Both species (here after referred to as ibis and pelican) are endemic to Australia and occur in inland wetlands (Marchant and Higgins 1990), but also in many coastal environments of eastern Australia (Corben and Munro 2008; McTaggart 2008). Ibis feed mainly on invertebrates, while pelicans feed on fish, crustaceans and cephalopods (Carrick 1959; Vestjens 1977). Today ibis and pelicans are common in urban parks and at landfills in Australia, where they forage for anthropogenic waste (Corben 2003; Ross 2004; Thomas 2007; McTaggart 2008). As both species are native, they are protected under both the *Nature*

Conservation Act 1992 and *New South Wales National Parks and Wildlife Act* 1974. Both species are colonial breeders. In their traditional breeding areas in inland Australia, breeding is triggered by flooding of inland wetland systems (Carrick 1962; Vestjens 1977).

Study sites

Landfills

The following three major landfills for household waste were monitored in the Sydney region: Belrose (BR) (33°43'S, 151°13'E), Eastern Creek (EC) (33°49'S, 150°52'E) and Lucas Heights (LH) (34°3'S, 150°58'E). BR (~30 ha, operating since 1974), EC (~154 ha, operating since 1984) and LH (~16 ha, operating since 1987) are some of Australia's largest landfills and receive approximately 200,000, 7-800,000 and one million tonnes (t) of household waste per year, respectively (WSN 2008). BR, EC and LH have an exposed 'tip-face' area of 250, 1000 and 1000 m^2 and operate between 07:00-13:00, 06:00-16:00 and 06:00-16:00 daily, respectively (WSN 2008).

Two further landfills in the Brisbane Water region (40 and 47 km north-north-east of Sydney) were monitored: Kincumber (KC) (33°29'S, 151°24'E) and Woy Woy (WW) (33°31'S, 151°17'E). They are the main landfills for household waste in the Gosford area (Fig. 1). The Kincumber (18 ha, operating since 1977) and Woy Woy landfill (50 ha, operating since 1974) receive a combined amount of 180,000 t waste per year, which contains on average 40% food waste (GCC 2008). The Kincumber landfill operates between 08:00-16:00 (daily); and the Woy Woy landfill operates between 07:00-17:00 (Mon-Fri) and 08:00-16:00 (Sat-Sun) (GCC 2008). Waste deposition was terminated at Kincumber in August 2009 and will finish at Woy Woy after 2018 (GCC 2008).

The ‘tip-face’ of each landfill is covered by soil (~15 cm thick) at the end of each day. All landfills contain ponds of water, which attract birds.

<u>Roosting/breeding colony</u>

We also monitored a major roosting/breeding colony of ibis and pelicans (between May and July 2007) (Thomas 2007; McTaggart 2008) at a sand island (SI) (33°30’S, 151°20’E) in Brisbane Waters between KC and WW (Fig. 1). KC is 7 km northeast and WW 5 km west of SI. Due to the proximity of the sites to each other, and preliminary observations that suggested that large numbers of ibis from SI were feeding on both landfills, we decided to calculate the proportion of the total ibis population that was using both landfills.

Data collection

BR, EC and LH were visited between 10:00 and 14:00 once per week (week days only) between 5 September and 30 December 2005 (late breeding period for ibis and pelicans), and the total number of all species and their abundances on each landfill were recorded using binoculars (magnification 10X40, Zeiss, Germany). For ibis, we also determined the population’s age composition by calculating the percentage of juveniles and adults from a random sub-population of 100 birds during each visit. At these visits we also recorded the feeding rates of ibis. This was done by randomly selecting three ibis during each visit and counting how many items from the tip-face they swallowed in three minutes.

KC and WW were visited between 11:00 and 13:00 on the same day once per week (week days only) between 3 March and 27 July 2007 (early breeding period for ibis and pelicans), and the number of species and their abundances were recorded. The sites were monitored shortly after each other (approximately 40 minutes apart) in order to obtain the most accurate measure for total abundances. To gain an estimate of the proportion of the ibis population that uses the landfills located at the Central Coast, we counted the number of ibis on and near SI prior to our counts on the landfills. We also counted the overnight roosting population of ibis at SI once per week (week days only) from 3 May to 27 July 2007. This was done by combining the number of ibis present on SI two hours before dusk with the number of ibis that flew on to, minus the number that flew off SI before sunset (for details, see Corben 2003; Corben and Munro 2008).

Data analysis

Firstly, we listed all species for each site. From this list we selected the two most common species (ibis and pelican) and calculated from their weekly abundances their average monthly abundances ± standard error (s.e.) at each landfill (Fig. 2 and 3). Monthly abundances of both species were compared separately for each site with a repeated-measures ANOVA (Wilks' lambda) (SPSS version 14.0). The two regions (Sydney and Brisbane Waters) were compared separately because of the differences in time of the year that they were monitored. For the landfills in Sydney (BR, EC and LH) we also calculated the percentages of juvenile, during each month, and tested for differences between months with a repeated-measures ANOVA followed by Bonferroni Pairwise Comparisons. Where the assumptions for the repeated-measures ANOVA were violated, a Friedman test followed by a Mann-Whitney *U* test were used to determine whether juvenile percentages differed between months. The level of significance for all tests was set at 0.05. When abundances of both ibis and pelicans did not differ significantly between months ($P > 0.05$; Mann-Whitney *U* test), weekly abundances of each site (within regions) were grouped, so that the average ± standard deviation (s.d.) population size could be calculated.

The proportion of the population of ibis that used the KC and WW landfills during each week was determined by dividing the number of ibis at the landfills by the number of ibis roosting at SI overnight. These proportions were converted into percentages. From these weekly values, we calculated monthly average percentages ± s.e. of the ibis population at both landfills. A Friedman test was used to determine if there was a significant difference in the average percentage of ibis at the landfills between months. We also calculated from the weekly percentages of ibis at the landfills an overall average percentage of ibis ± s.d. for all months.

In order to understand how the location of the landfills relates to the urban ibis population, we also mapped the location of the major breeding colonies (≥100 birds; Geoff Ross NPWS pers. obs.) and range of ibis in the wider Sydney region (new atlas data, January 1998 to February 2008; Birds Australia, Melbourne) with the ArcGIS mapping program (Version 9.2). Nesting site information was provided by Geoff Ross (Department of the Environment and Climate Change). The map template and urban area was obtained from Geoscience Australia (2008).

For the sites in the Sydney region (BR, EC and LH), we calculated on a monthly basis, the abundances and percentages of ibis on the tip-face, and their feeding rates. We compared each parameter between sites using a one-way ANOVA, followed by a Tukey HSD. Where the assumptions for the one-way ANOVA were violated, a Kruskal-Wallis test was used.

Results

Species diversity

The Australian white ibis and Australian pelican were the most common birds at each landfill. Other species sighted in lower numbers (on average less than 20 individuals per visit) included the silver gull (*Larus novaehollandiae*) and Australian raven (*Corvus coronoides*). Many other species occurred at the landfills, such as raptors (e.g. whistling kite (*Haliastur sphenurus*)), pigeon (*Columba livia*), finches (e.g. red-browed finch (*Neochmia temporalis*)) and other passerines (e.g. Indian myna (*Acridotheres tristris*)), however, none of these species were common or fed from the tip-face.

Abundances of ibis

While BR and LH had similar numbers of ibis (on average 248 ± 22 s.e.; range: 125-436, and 247 ± 24 s.e.; range: 141-460, respectively), EC had approximately six times as many (1485 ± 87 s.e.; range: 925-2236) during September – December 2005. Abundances at each site did not change significantly between September – December 2005: (a) BR ($F_{3,1} = 8.8$, $P = 0.241$), (b) EC ($F_{3,1} = 0.1$, $P = 0.941$), and (c) LH ($F_{3,1} = 5.1$, $P = 0.313$, repeated-measures ANOVA) (Fig. 1*a*). Therefore, we combined the results of all sites for each month. Again abundances did not differ between months ($F_{3,1} = 2.1$, $P = 0.465$, repeated-measures ANOVA) (Fig. 1*a*). The combined population of ibis at these three large landfills averaged 1981 ± 355 s.d.; range: 1228-2642 ($n = 16$).

In the Brisbane Waters region, WW (446 ± 39 s.e. ibis) had on average 100 more ibis than KC (346 ± 35 s.e. ibis), while SI had only 177 ± 27 s.e. ibis during the day between March - July 2007. The total ibis population of these sites, changed significantly between months ($\chi^2_4 = 13.00$, $P = 0.011$, Friedman test) (Fig. 2*a*). It doubled from an average of 536 ± 45 s.e. ibis in March 2007 to 1105 ± 41 s.e. ibis in May 2007. From then on (June and July 2007) it remained stable, even though ibis numbers at KC, SI or WW changed (Fig. 2*a*). Significantly more ibis were at SI during June and July than during any other month ($\chi^2_4 = 12.6$, $P = 0.013$, Friedman test).

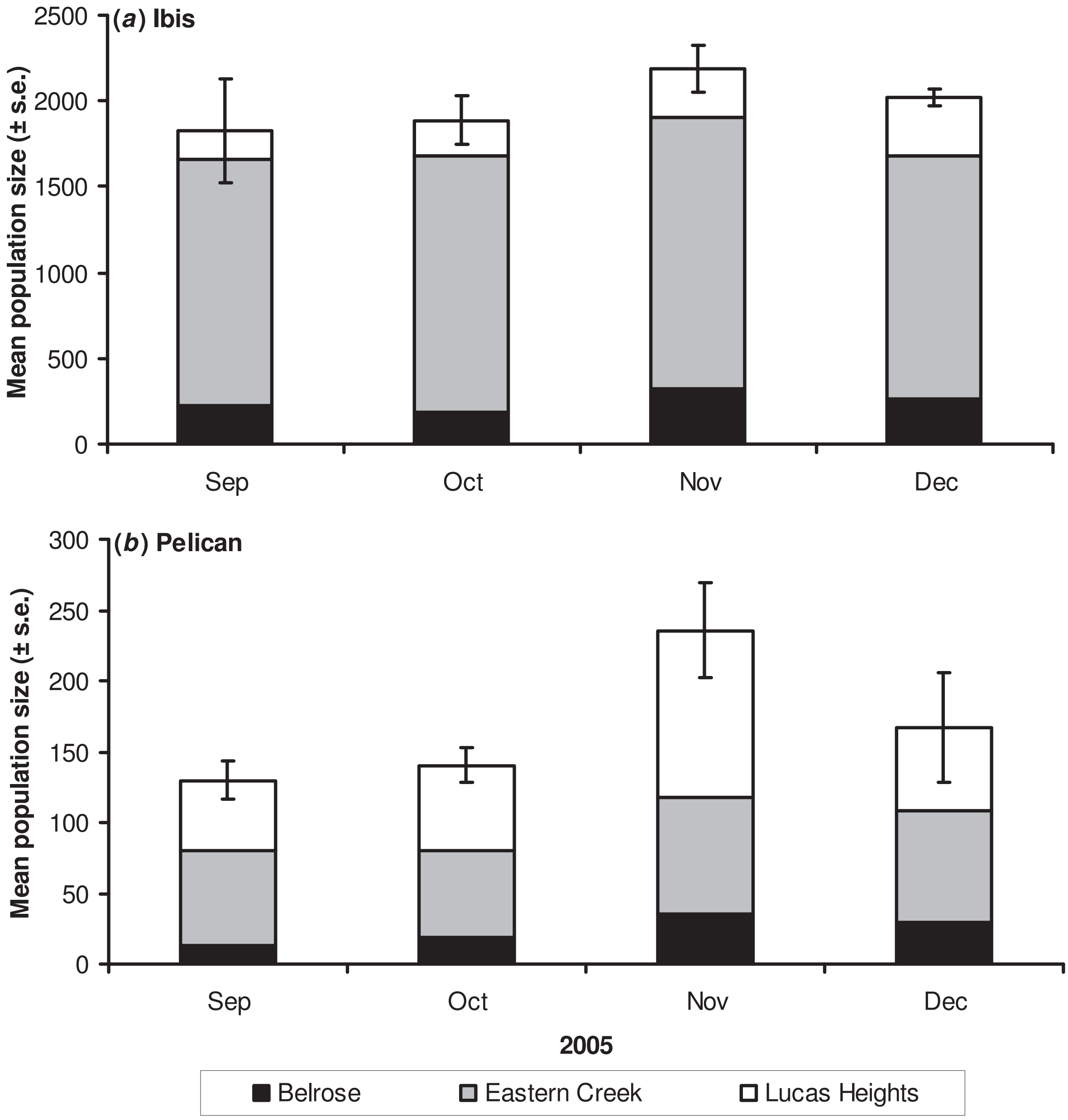

Fig. 1. Mean population sizes (± s.e.) of the (*a*) Australian white ibis, and (*b*) Australian pelican at three major landfills (Belrose, Eastern Creek and Lucas Heights) in Sydney.

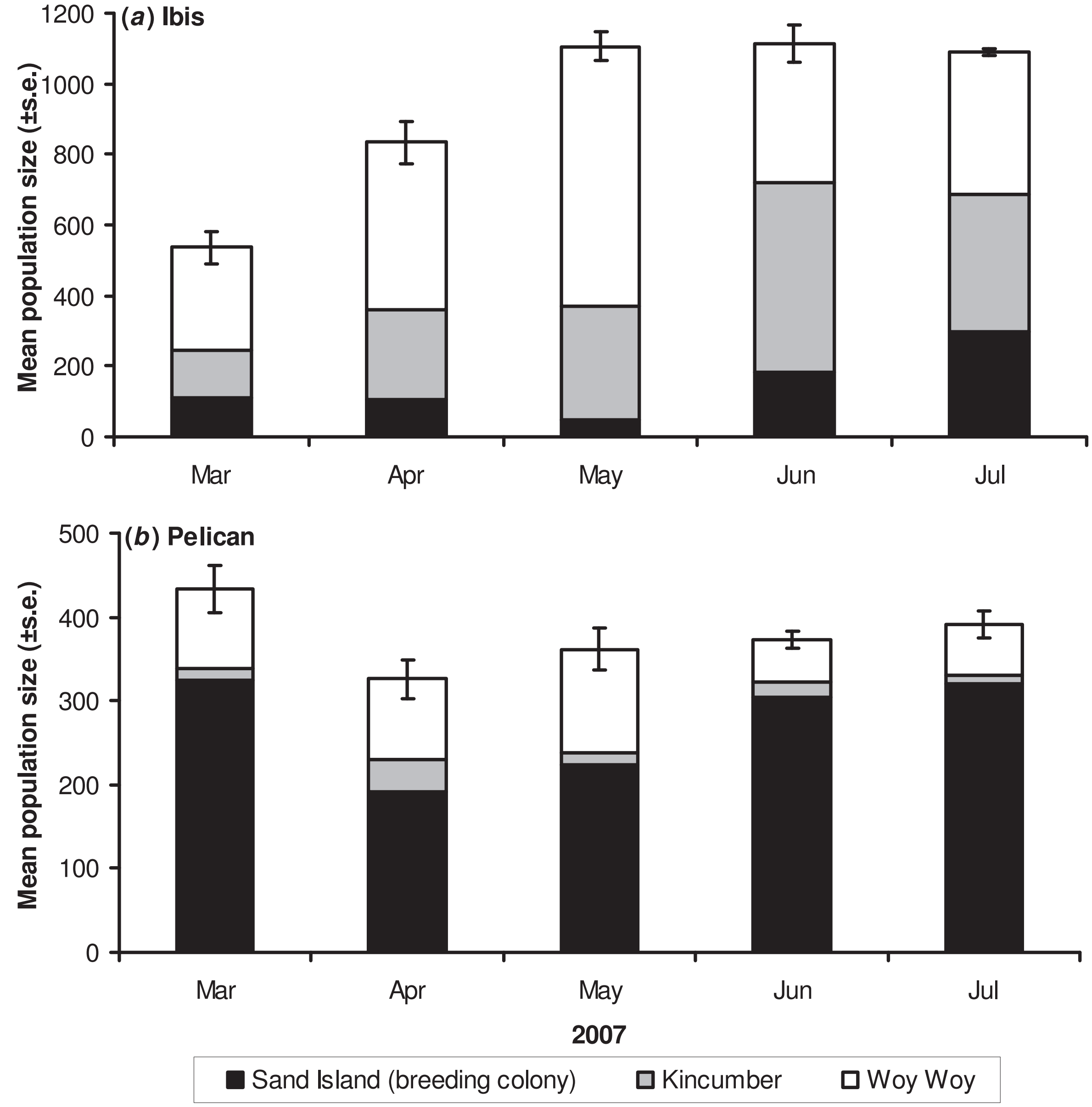

Fig. 2. Mean population sizes (± s.e.) of the (*a*) Australian white ibis, and (*b*) Australian pelican at two major landfills (Kincumber and Woy Woy) and a breeding colony (sand island) in the Brisbane Waters region.

Age composition of ibis

Juvenile ibis occurred at every landfill in Sydney. There was a significant difference in the proportion of juveniles between Sydney's landfills (BR, EC and LH) ($F_{2,45} = 6.1$, $P = 0.004$, one-way ANOVA). On average the percentages of juveniles at both EC (12.60% ± 3.15 s.e.)

and LH (10.02 ± 2.51 s.e.) were significantly higher than at BR (5.19% ± 1.29 s.e.) (Tukey HSD; $P = 0.012$ and 0.010, respectively). We found no significant changes in the percentages of juveniles in the total population between months at BR ($F_{3,1} = 0.1$, $P = 0.972$), EC ($F_{3,1} = 1.0$, $P = 0.605$), and LH ($F_{3,1} = 3.5$, $P = 0.369$, repeated-measures ANOVA).

Abundances of pelicans

The average number of pelicans at BR (24 ± 4 s.e.; range: 8-63) during September - December 2005 was significantly lower than that at EC (73 ± 8 s.e.; range: 28-156) and LH (72 ± 11 s.e.; range: 19-174) ($F_{2, 45} = 12.1$, $P < 0.001$, one-way ANOVA) (Fig. 2*b*). Pelican numbers at each landfill did not change between months (September – December 2005) (BR ($F_{3,1} = 3.2$, $P = 0.906$), EC ($F_{3,1} = 0.1$, $P = 0.299$), and LH ($F_{3,1} = 6.7$, $P = 0.953$, repeated-measures ANOVA)). However, when the weekly counts were combined and compared between months, we found significantly more pelicans during November 2005 than September 2005 ($F_{3,5} = 7.4$, $P = 0.028$, repeated-measures ANOVA; $P = 0.040$, Bonferroni Pairwise Comparisons).

In the Brisbane Waters region, pelican populations differed between sites, with an average population size of 18 ± 3 s.e. (range: 4-65) at KC, 271 ± 15 s.e. (range: 140-350) at SI, and 83 ± 7 s.e. (range: 22-155) at WW ($n = 22$) during March - July 2007 ($\chi^2_2 = 55.8$, $P = 0.006$, Kruskal-Wallis test) (Fig. 3*b*). When numbers for all sites were combined the pelican population in this area averaged 372 ± 59 s.d. birds (range: 235-498). No differences in abundances were detected between March - July, 2007 ($\chi^2_4 = 7.2$, $P = 0.126$, Friedman test) (Fig. 3*b*).

Extent of landfill use by ibis

On average, there were 46.25 ± 7.50 s.e (May), 183.25 ± 38.50 s.e. (June), and 298.75 ± 39.39 s.e. ibis at SI during the day. However, the roosting population averaged 1146.50 ± 13.82 s.e (May), 1201.50 ± 29.03 s.e. (June) and 1289.25 ± 32.00 s.e. (July). The majority of ibis roosting at SI overnight spent the day at either KC and WW. On average 92.23% ± 3.21 s.e. (May), 77.46% ± 4.32 s.e. (June), and 61.63% ± 3.90 s.e. (July) of the ibis roosting at SI overnight occurred on the landfills, with percentages differing significantly from May to July 2007 ($\chi^2_2 = 8.00$, $P = 0.018$, Friedman Test). Over all months, 77.14% ± 14.81 s.d. (range: 58-99%) of the SI ibis population spent the day at either the KC or WW landfill. The number of ibis counted at SI, KC and WW during the day amounted to 95.86% ± 4.35 s.e. (May), 93.35% ± 6.55 s.e. (June) and 84.65% ± 1.81 s.e. (July) of the population that roosted at SI overnight. This means that our counts at SI, KC and WW included most birds of the roosting population, and provide a good estimate for calculating the percentages of birds that use landfills.

Distribution of ibis in the Sydney area and spatial relationship between landfills and breeding colonies

Most ibis sightings (atlas data 1998-2008) in the wider Sydney region occur within the urban environment (Fig. 3). All major breeding colonies are also within or adjacent to urban areas and close to landfills. There are at least nine major breeding colonies within the Sydney region (Fig. 3), namely Annan Lake (34º3'S, 150º46'E), Burwood Park (33º52'S, 151º6'E), Cabramatta Creek Reserve (33º55'S, 150º56'E), Centennial Park (33º54'S, 151º14'E), Darling Harbour (33º52'S, 151º12'E), Lake Gillawarna (33º55'S, 150º59'E), Marrickville (33º55'S, 151º10'E), Royal Botanical Garden (33º52'S, 151º13'E) and Sydney Olympic Park (33º51'S, 151º4'E).

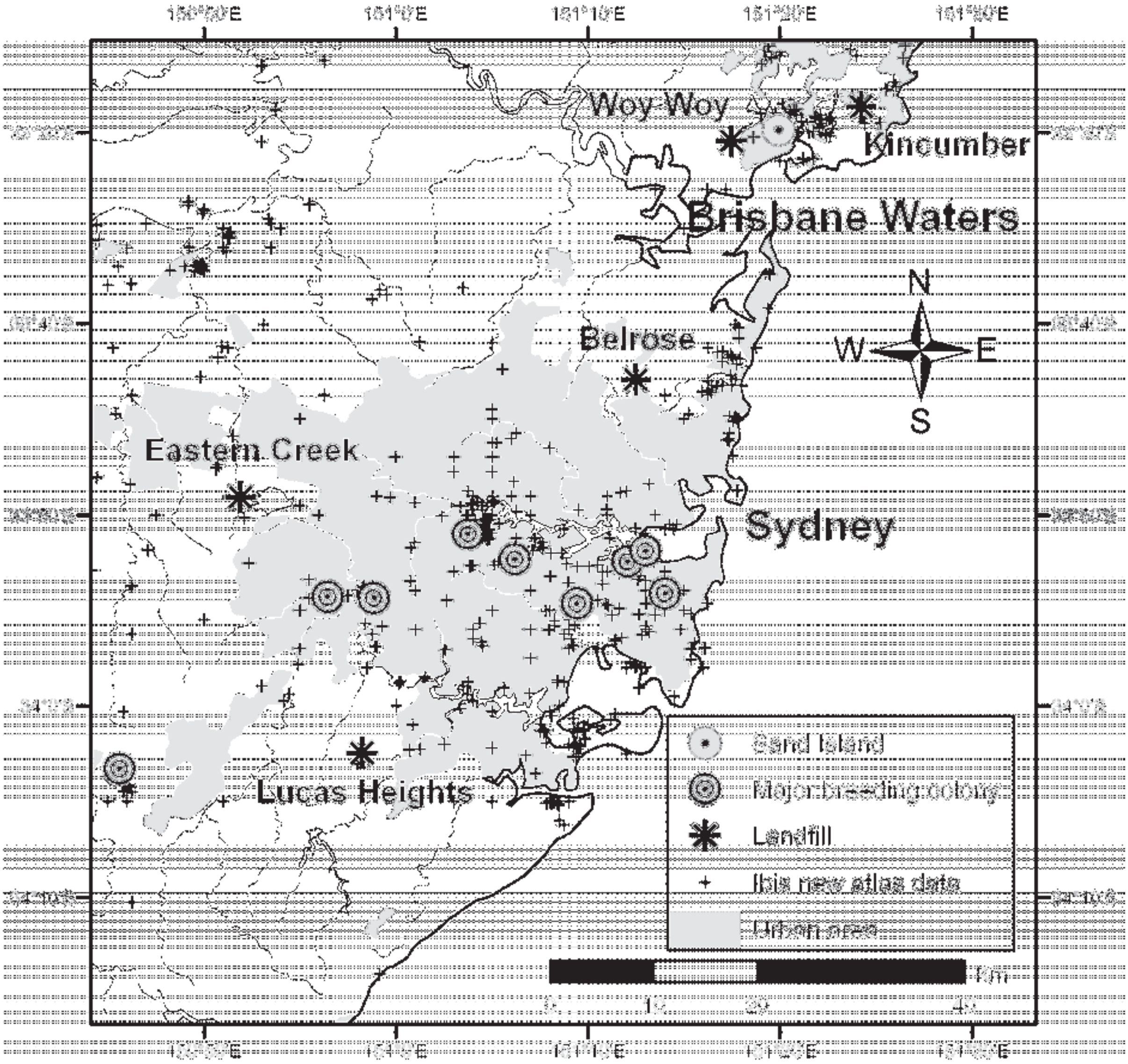

Fig. 3. Major landfills for household waste and breeding colonies (>100 nests) of the Australian white ibis in the Sydney and Brisbane Waters regions, Australia. The sand island (SI) hosted a large breeding colony of ibis and pelicans. Crosses (+) indicate locations of ibis sightings (bird atlas data between January 1998 and February 2008). The grey shaded area roughly indicates the urban areas.

Abundances of ibis at the tip-face

The average number of ibis on the tip-face was 131.31 ± 10.16 s.e. (range: 43-219) at BR, 584.47 ± 56.86 s.e. (range: 334-1042) at EC, and 113.35 ± 8.95 s.e. (range: 50-187) at LH (n = 16 counts at each landfill). Numbers of ibis feeding on the tip-face did not differ between months (September - December 2005) (BR ($F_{3,1}$ = 0.5, P = 0.749), EC ($F_{3,1}$ = 10.3, P =

0.225), and LH ($F_{3,1}$ = 0.6, P = 0.713; repeated measures ANOVA)). EC had significantly more ibis on the tip-face than BR and LH ($F_{2,49}$ = 64.8, P < 0.001, one-way ANOVA). However, the percentage of birds on the tip-face at EC (calculated from the overall number of birds at the landfill) was significantly less (48.76% ± 3.96 s.e.) than that at BR (62.89% ± 5.09 s.e.) and LH (61.41% ± 6.66 s.e.) ($F_{2,49}$ = 2.42, P = 1.00, one-way ANOVA). Average densities of ibis on the tip-face (number of ibis per m^2 of tip-face) differed. BR (0.53 ibis per m^2 ± 0.04 s.e) and EC (0.58 ibis per m^2 ± 0.06 s.e) had significantly higher densities of ibis, than LH (0.11 ibis per m^2 ± 0.01 s.e) (χ^2_2 = 31.1, P < 0.001, Kruskal-Wallis test).

Feeding rates of ibis

The feeding rates (food items swallowed per minute) at BR, EC and LH averaged 1.99 ± 0.29 s.e., 1.76 ± 0.23 s.e. and 1.56 ± 0.21 s.e., respectively, and did not differ between sites ($F_{2,123}$ = 0.8, P = 0.467, one-way ANOVA). The combined feeding rate of ibis for all landfills averaged 1.77 ± 1.58 s.d. (range: 0-8) (n = 144).

Discussion

Species diversity

Our results show that the Australian white ibises and Australian pelican are the most prominent birds on landfills in the wider Sydney region, while gulls, corvids (which are usually common on the world's landfills (Meyer *et al.* 2003)), and other species occur in low numbers. Ibis, as many other members of the ciconiiformes, are known to forage at landfills (Kentish 1994; Ross 2004; Corben and Munro 2006; Murray and Shaw 2006; Epstein *et al.* 2007). Other ciconiiformes that feed at landfills include the closely related sacred ibis (*T. aethiopica*) (Urban 1974), as well as the cattle egret (*Bubulcus ibis*) (Feare 1975; Pomeroy 1975; Burger and Gochfeld 1983; Yorio and Giaccardi 2002), pied heron (*Ardea picata*) (P.

Shaw (Ecosure), pers. comm.), marabou stork (*Leptoptilos crumeniferus*) (Pomeroy 1975), white stork (*Ciconia ciconia*) (Blanco 1996; Tortosa *et al.* 2002, 2003); white-face heron (*Egretta novaehollandiae*) (T. Soloman; pers. comm.). This makes the ciconiiformes (with respect to species numbers) the third most prevalent group of birds on landfills after gulls and corvids.

The pelican was the second most abundant bird at our landfills. Prior to our investigations there is no account of pelicans using landfills in Australia in the literature, even though landfill operators have sighted them on landfills, at least in the Sydney region, since the early 1990's (WSN 2008). Furthermore, no pelican species from other parts of the world have ever been reported to feed at landfills. Pelicans are known to be opportunistic feeders and eat besides fish and aquatic invertebrates a wide variety of items (e.g. small birds, bread, meat and dogs) (Young 2004; McTaggart 2008; Smith and Munro 2008). Consequently, feeding from landfills, where often large amounts of meat waste are available (Meyer *et al.* 2003), does not seem surprising. It is likely that other landfills in Australia also host pelicans or may do so in the future. Pelican sightings at a landfill at Townsville, Queensland, (P. Shaw (Ecosure), unpubl. data) and Lyndhurst, Victoria (since at least 1990) (Daniel Fyfe (SITA Environmental Solutions), unpubl. data) suggest pelicans feed at landfills at other parts of Australia.

Silver gulls were uncommon (less than 20 individuals per visit) at our landfills. This was surprising, in particular since Smith and Carlile (1993) reported >6000 gulls at a landfill ~70 km south of Sydney, and high numbers of resident silver gulls occur in Sydney's urban areas (Smith and Carlile 1992; pers. obs.). Gulls are also common at landfills (Smith and Carlile 1992) world wide, and at least 11 other species of gulls are known to feed at landfills, including the Audouin's (*L. audouini*) (Blanco and Marchamalo 1999), brown-hooded (*L. maculipennis*) (Yorio and Giaccardi 2002), California (*L. californicus*) (Strong *et al.* 2004), glaucous-winged (*L. Glaucescens*) (Murphy *et al.* 1984), greater black-backed (*L. marinus*) (Harris 1965), herring (*L. argentatus*) (Harris 1965; Brown 1967; Spaans 1971; Belant *et al.* 1993, 1995, 1998; Gabrey 1997), kelp (*L. dominicanus*) (Coulson and Coulson 1998; Bertellotti *et al.* 2001; Yorio and Giaccardi 2002), lesser black-backed (*L. fuscus*) (Harris 1965; Brown 1967), Pacific (*L. pacificus*) (Coulson and Coulson 1998), ring-billed (*L. delawarensis*) (Belant *et al.* 1995, 1998; Brousseau *et al.* 1996; Gabrey 1997) and yellow-legged gull (*L. michahellis*) (Bosch *et al.* 1994; Duhem *et al.* 2005, 2007, 2008). Despite the gulls' common occurrence at landfills we never recorded them in large numbers at Sydney's landfills.

It is not known why abundances of silver gulls at landfills in Sydney were low. The high number of ibis and pelicans could be one reason. Both species are considerably larger than gulls and aggressive and may exclude gulls. Also, pelicans are known to feed on other birds (Smith and Munro 2008), and may pose a direct threat to gulls. Direct competition for food is another option, with ibis and/or pelicans causing a similar decline in silver gulls, as the large and aggressive kelp gull has at Tasmania's landfills (Coulson and Coulson 1998). Another possibility is that silver gulls have abandoned landfills because operators employed gull scaring devices. At EC, which hosted ~5000 gulls in the past, gull distress calls have been used since the mid 1980's to discourage gulls from using the site (WSN, unpubl. data).

The presence of the Australian raven at the landfills was not unexpected. Ravens are inquisitive scavengers (Kaczensky *et al.* 2005). The Torresian crow (*Corvus orru*), another Australian species (P. Shaw, pers. comm.), plus five other species of corvids from around the world use landfills, including the American crow (*C. brachyrynchos*) (Harlow *et al.* 1975; Stouffer and Caccamise 1991; Belant *et al.* 1995; Gabrey 1997; Withey and Marzluff 2005), common raven (*C. corax*) (Harlow *et al.* 1975; Restani *et al.* 2001; Webb *et al.* 2004), hooded crow (*C. corone*) (Vuorisalo *et al.* 2003), pied crow (*C. albus*) (Pomeroy 1975), and rooks (*C. frugilegus*) (Olea and Baglione 2008). In some corvids the use of landfill has lead to population increases (Withey and Marzluff 2005; Olea and Baglione 2008). Whether this is also the case for any Australian corvids is not known, since no detailed studies are available. All other species recorded at the landfills were either raptors or smaller birds that were not feeding from the tip-face.

Ibis and pelican abundances

Prior to our investigations no detailed reports on the abundance of ibis and pelicans on landfills were available. Numbers for both species were considerable, especially for ibis, and highlight the importance of landfills for these birds. EC hosted more ibis (above 1500 during each month) than the other two Sydney landfills (BR and LH), rendering it the most significant site in Sydney for ibis. It is not known why ibis preferred EC to the other landfills. Average flying distances from the major breeding and roosting sites are similar to all landfills and cannot account for the differences in their abundances. It may be that a larger tip-face (e.g. EC) provides easier access to food than a smaller tip-face (BR). However the largest site (LH) had similar numbers of ibis than BR, thus the amount of waste cannot be the sole reason for the preference of EC. Another reason may be habitat differences between landfills and access to water. EC, for example, has several large ponds that attached larger numbers of ibis than the ponds at other landfills (pers. obs.). Since ibis have also bred at EC in the past, but not at the other landfills (pers. obs.), it appears they prefer this landfill to others.

Currently it is not known, which factors increase the attractiveness of landfills, and future studies need to focus on this.

In the Brisbane Waters region, the overall increase in ibis numbers from March to May was probably from an influx of breeding birds into the area, as has also been proposed by Corben and Munro (2008). The increase of ibis on SI during June and July was most likely due from adults remaining at the island during the day to attend their nests and brood (Thomas 2007). Ibis showed no clear preference for either the WW or KC landfill, and abundances at both landfills were roughly similar (except May when the WW landfill was preferred) (Fig. 2*a*). Abundances at these landfills were also similar to those at BR and LH in Sydney, which suggests that these landfills can carry ~500 ibis. However, EC and other landfills in the northern part of New South Wales and southern Queensland can host much higher number of ibis, with one landfill recording over 6000 ibis at one stage (Ecsoure 2009). It is likely that ibis breeding colonies in many other urban centres of Australia are sustained by their local landfills.

The pelicans occurred in significantly higher numbers at EC, LH and WW than both BR and KC. BR and KC are small landfills and probably receive far less waste than large landfills, which could account for the low numbers. While size differences and waste availability make it plausible for pelicans selecting WW over KC, WW is also closer to SI than KC. Since pelicans are large birds, with high energy costs for flight (Weimerskirch *et al.* 2001), the shorter distance to the WW landfill may also influence their choice of feeding site. SI and a colony 80 km south of Sydney (Five Island near Wollongong) with up to 300 birds during the breeding period (N. Carlile, pers. comm.) are the closest colonies to Sydney and probably sustain the birds that feed on Sydney's landfills.

Extent of landfill use of ibis

The KC and WW landfill appear to sustain the ibis population that roosts at SI, with 77% (range: 58-99%) of the roosting population visiting these landfills during the day. This coincides with observations from Ecosure (2009), which reported that 66-78% of ibis feed at landfills at the Gold Coast, Queensland. It appears that almost all ibis of our study use landfills and only occasionally feed on mud-flats during low-tides and grass areas. The reliance of urban ibis on landfills needs to be considered when managing this species. The obvious solution for reducing ibis numbers appears to limit their access to landfills, as already suggested by Ecosure (2009). While no appropriate and effective method of access restriction is yet available, drastically reducing their numbers may harm the existence of this native species (Martin *et al.* 2007). At present ibis have declined dramatically in their traditional breeding areas in Australia's inland wetlands (Porter *et al.* 2006) and urban populations may sustain the survival of the species (Corben and Munro 2008). If ibis are not tolerated, and allowed to live in our cities and feed on landfills, the species may decline to unsustainable levels.

Ibis distribution

Ibis and their breeding colonies mainly occur in urban parts of Sydney and in close proximity to landfills (Fig. 1). Nesting sites are located between landfills and allow ibis to visit different landfills without travelling far from their roosting/breeding colony. The spatial arrangement of the breeding and landfill sites highlights that restricting access to ibis at a single landfill will have little effect on them. Most likely ibis will forage at another landfill and worsen the problem there. Management will probably only be effective when a broad scale approach is used, and all landscapes are concurrently managed for ibis.

Ross (2004) proposed that ibis started to move towards the coast and urban centres, as much of their traditional habitat has been adversely affected by drought and poor water management, and breeding areas have been degraded or lost (Kingsford and Johnson 1998). It is not known when ibis began to use urban landfills. However, landfill use by ibis and other species (e.g. pelicans) may increase in the future, since climate change may lead to even more severe and frequent droughts and habitat destruction (Finlayson *et al.* 2006), while at the same time the demand for water for farming and irrigation increases (Roshier *et al.* 2002).

Juvenile ibis

The high proportion of juvenile ibis at Sydney's landfills indicates that landfills are important sites for them. Landfills can offer a reliable food source for these inexperienced birds (Webb *et al.* 2004). Studies of a related species, the American white ibis (*Eudocimus albus*), revealed that juvenile feeding in natural habitats (mud flats) are less successful than adults (Bildstein 1983 and 1984), so feeding at landfills may be an easy option. Landfills are also important for juveniles of other species, such as common ravens (Webb *et al.* 2004), silver gulls (Smith and Carlile 1993), and white storks (Blanco 1996). Landfills provide reliable food sources and dramatically reduce the level of skills and efforts required by a species to meet its daily food requirements. This can lower juvenile mortality rates, increase recruitment into the adult population (Smith and Carlile 1993; Blanco 1996; Webb *et al.* 2004), and subsequently lead to superabundances (Belant *et al.* 1993; 1998; Duhem *et al.* 2008). It may also produce birds, which do not have the skills to feed in natural environments, and become dependent on landfills or other anthropogenic food sources.

Abundance of ibis at the tip-face and feeding rates

As there is no monthly variation in the number of ibis on each tip-face, the quantity of waste available to birds at each landfill may also vary little. EC had the highest number of ibis on the tip-face. Despite BR having a smaller tip-face than EC, they had similar densities (number of ibis per m^2) on their tip-faces. LH, with a same sized tip-face as EC, had a density of ibis four times less than BR and EC. This indicates that LH's tip-face is least preferred by ibis. We do not know why this is the case, lower amounts of eatable waste may be responsible.

Ibis were not frightened of any machinery and heavy vehicles (e.g. compactors and garbage trucks) operating on the landfill and tip-face, and foraged right next to them, even while they were operating. Similar has been described for cattle egrets at landfills (Burger and Gochfeld 1983). The feeding rates of ibis at the landfills were twice as high as in more natural habitats (Murray 2005). Burger and Gochfeld (1983) also studied feeding frequencies of birds at landfills, however, as their data were presented as 'the time between finding a food item', it cannot be directly compared to our results. However, if one divides one minute by the average 'time between finding a food item', results become comparable. In comparison to the eight other species (predominately gulls and corvids) that feed at landfills, ibis have a relatively low feeding success (Burger and Gochfeld 1983). However, since high feeding rates do not necessarily equate to a high food intake and feeding rates differ between different sized birds, feeding rates do not reflect the overall success of the birds. Ibis are considerably bigger than gulls and ravens, and probably take bigger food items and by doing so ingest large volumes. So comparing feeding rates should only occur between birds of equal sizes and with similar diets. Regurgitated food of ibis that fed at landfills contained large amounts of raw, cooked and processed meat waste (pers. obs.). This was also the case for pelicans with some items weighing up to 500 g (McTaggart 2008).

Conclusion

There are many ways to exclude wildlife, in particular birds, from accessing landfills and preventing them from feeding (Belant 1997; Baxter and Allan 2006, 2008; Baxter and Robinson 2007). Closing a landfill or preventing wildlife to feed on it can affect birds and other animals that are supported by the landfill (Vuorisalo *et al.* 2003; Ecosure 2009). This means that if access to landfills is restricted for ibis and pelicans, their numbers can decline. Since ibis and pelican are native, this needs to be considered, when trying to manage these birds. Due to the poor water management and a severe drought that has dominated most of these species' traditional breeding ranges for years (Kingsford and Johnson 1998), many species rely on the more permanent water bodies on the eastern coast of Australia as refuges (Ross 2004). The impact of preventing birds from accessing landfills, may exacerbate their population decline.

Currently, the management that focuses on reducing the breeding success of urban ibis by targeting their breeding colonies has had limited success. The birds probably relocate to other areas within the urban environment, sometimes worsening the problem (G. Ross, pers. comm.). Ross (2004) and Ecosure (2009) have suggested that limiting ibis from accessing landfills would reduce their numbers in the urban environment. This has also been concluded from studies on gulls feeding at landfill (Smith and Carlile 1993; Belant *et al.* 1995, 1998; Belant 1997; Coulson and Coulson 1998; Bertellotti *et al.* 2001; Duhem *et al.* 2008). However, it is largely unknown what impact this may have on ibis. It could result in more ibis using urban parks and other sources of anthropogenic food waste (e.g. other less managed landfills in Australia) or the species declining to unsustainable levels. Excluding birds from landfills is also logistically difficult and costly, because predominately aggressive and inquisitive bird species feed at landfills (Meyer *et al.* 2003) that are not easily discouraged.

Further studies are needed on the impact of landfills on local wildlife before effective management can occur in Australia. There is a level of urgency for such studies because landfills are likely to become more important in the future, as the human population grows and the amount of waste that humans produce increases. Also, it is likely that more species will adapt to using landfills out of necessity as climate change and other factors lead to further habitat degradation in Australia in the future.

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Chapter 7.

General Conclusion.

The Australian White Ibis (*Threskiornis molucca*) has increased its range dramatically since the 1970's and today occurs in all major Australian urban centres (Ross 2004; Murray and Shaw 2006; unpub. data). Its overabundance in urban environments causes many ecological, social and economical problems, which agencies with ibis problems need to address, when managing this bird (Corben 2003; Epstein *et al.* 2006; Martin *et al.* 2007). Since ibis are a native bird (Merchant and Higgins 1990), they are protected under both federal and state law (*Nature Conservation Act* 1992, *New South Wales National Parks and Wildlife Act* 1974) and management needs to ensure the survival of this species. Currently little is known about ibis from both urban and non-urban populations, which means that no baselines exist for appropriately managing this species (Corben and Munro 2008). In particular, information on the birds' breeding biology, abundance, age composition, feeding ecology and movements, which is required for the effective management of any species, is lacking. In my thesis I have focused on these parameters with the aim to increase our overall knowledge on ibis and provide the baselines needed for their management.

I have discovered that egg and clutch sizes, and hatching success are lower at urban than non-urban colonies (Lowe 1984; see chapter 2), while fledging success can be high in the urban environment (e.g. Lake Gillawarna). Reliable food resources at landfills may, at least to some extent, contribute to increased hatchling survival. Breeding success can vary between colonies and may not always be high, even though colonies (e.g. Woy Woy) may be large and close to landfills. Other environmental factors (e.g. high predation, exposure to unfavourable weather, flooding of the island) may be suppressing breeding success. This means that large colonies do not necessarily have a high reproductive output and in all cases need management. Prior to any management, reproductive success needs to be assessed, so that cost and labour input does not outweigh management outcomes. My findings also highlight that several colonies need to be studied to obtain an accurate understanding of the breeding success of ibis in the urban environment. Success can vary significantly between colonies, and may also be influenced by intraspecific brood parasitism (chapter 3), during which birds actively transfer already laid eggs between nests in their bill. While there is some evidence that other birds do similar (Shield 1987), researchers considered this unlikely (Jackson 1985), and no detailed studies on this behaviour is available. My findings provide the strongest evidence today that birds can move eggs between nests and highlight the need for further studies into this phenomenon.

I found large variations in both the population abundance and age composition of breeding/roosting colonies over time (see chapter 4). This means that colonies need to be monitored regularly to understand their population dynamics, and provide appropriate baselines for management. Afternoon fly-in counts of ibis into their overnight roosts are best to estimate total population sizes and can also indicate the location of the feeding sites they use during the day. In general, the ibis approached their roots from the direction of nearby landfills.

Although the breeding success of ibis in the urban environment appears to contribute to their current increase, there is also evidence that the majority of juveniles are leaving after breeding and travel long distances, which can take them as far as Papua New Guinea (see chapter 5). It is likely that the young birds do not return to their breeding site until they reach sexual maturity (i.e. when at least two years old). Prior to their departure young as well as old birds travel throughout the urban environment and frequently visit major landfills for household waste.

Ibis appear to use multiple roosting and feeding sites, and may even change breeding sites within the wider Sydney region (see chapter 5). This may allow them to quickly change roosting and breeding sites, should management occur. This is important to consider when managing this species. If birds can quickly move to other sites, discouraging them from one area may simply spread them and the problems associated with them to other areas and not solve the problem. In the worst case fragmentation of the population can be the result, as has been reported for other species (Clergeau 2005), and instead of having localised problems, they may be spread over a large area. Thus, management of this species needs to have a regional focus, taking into consideration multiple sites and also address their access to domestic waste from landfills.

This thesis provides the first comprehensive study that adequately links the presence of ibis in the urban environment to landfills (see chapter 5 and 6). Landfills appear to provide a significant proportion of food for adult and young ibis and may sustain large populations in urban environments. It is not clear yet whether their heavy reliance on waste has any ill effects on the birds. Severe leg deformities observed in some hatchlings may indicate this, but further investigations need to be conducted, before any conclusions can be reached.

While I have provided in my thesis substantial information on the biology of ibis and baselines for management strategies, further research needs to concentrate on:

- the breeding biology of ibis at more urban (e.g. small and non-permanent) and non-urban colonies;
- the possible reasons for low egg volumes, clutch sizes and hatching success in urban colonies;

- paternity testing of chicks from large clutches to better understand the breeding systems of ibis;
- mortality rates of ibis, so that populations can be modelled and their status projected;
- satellite tracking of both juvenile and adult ibis to identify their movements; and
- abundances and feeding success of ibis and other species at landfills and effects on the birds' health, survival and juvenile development.

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