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The use of cattle ear-tags as patagial markers for large birds-a field assessment on adult and nestling Australian White Ibis

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Abstract

To test the effectiveness of patagial marking with cattle ear-tags for Australian White Ibis (Threskiornis molucca), 105 adults and 58 nestlings were fitted with tags on each wing. Resighting frequency of adults, survival of nestlings, breeding behavior and foraging movements were monitored. The resighting frequency of wing-tagged adults was compared with resightings of 160 adults marked with colored leg-bands. Survival rates of wing-tagged nestlings were compared with an equal sample of 58 nestlings fitted with colored leg-bands. Over six months, 96% of tagged adults were resighted and there was no indication of impaired flight, with foraging movements ranging up to 30 km. Wing-tagged adults were more likely (40%) than color-banded adults (28%) to be detected in a one-off survey three months after marking and 65% of tagged birds were observed nesting. Higher mortality was observed among smaller nestlings (<1100 >g) compared with larger nestlings marked with wing tags, but not among those marked with leg bands. Inspection of the wings of two adult and two juvenile birds recaptured 6-8 months after marking indicated only minor feather abrasion, although further study is needed to assess long-term impacts. Because patagially-fitted cattle ear-tags are more visible than colored leg bands, can be fitted quickly with minimal trauma, and seem to have few adverse effects, they appear to be an effective technique for individually marking large adult birds.

Keywords

white, tags, australian, nestling, ear, adult, ibis, assessment, cattle, field, large, markers, patagial, birds

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

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Population and breeding trends of an urban coloniser: the Australian white ibis

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Abstract

Context. In the Sydney region, the population of Australian white ibis has dramatically increased from rare observations in the 1950s to a breeding season peak of 8900 in 2008, resulting with human–wildlife conflicts. Within natural habitats across the eastern states, the ibis population has declined, yet within urban environments ibis have been lethally managed for over 30 years. However, limited ecological and no regional population data are available for the Sydney region.

Aims. The present study of ibis in the Sydney region aims to (1) establish the abundance of the population during the breeding and non-breeding seasons, (2) determine whether the population is increasing, and (3) identify the importance of different foraging and roosting sites.

Methods. Across the Sydney region, we surveyed 54 discrete sites for 2.5 years. At each site, we recorded the number of adult, juvenile and nestling ibis as well as the number of active nests. The 54 sites were grouped into 15 areas consisting of five landfills and 10 suburbs, which were assessed with ANOVA.

Key results. The ibis population of the Sydney region doubled from a peak of 4200 in 2006 to 8900 in 2008. Seasonal fluctuations saw adults migrating in to the region to breed, and adults and juveniles dispersing following breeding. On average, 44% of the population was located foraging within landfills, whereas 80% of nesting activity occurred within 'urban-natural' habitats.

Conclusions. Seasonal fluctuations indicated that the ibis population of Sydney is connected with the broader state and national population. Landfills provided an abundant foraging resource that supported extended breeding, including consistent nesting for a 19-month period.

Implications. The present study indicated that any localised population management has consequences beyond the immediate or regional population and, consequently, regional management plans or actions need to consider the long-term status of the eastern states' population. Urban conflicts need to be resolved with human education and a conservation agenda, preferably with the provision of refuge habitat where birds are not disturbed.

Introduction

A cornerstone of good wildlife management decisions by land managers and regulatory government agencies alike is an understanding of a species' population size, age structure and distribution (Krebs 1999). Variables including whether a population is increasing or decreasing locally and across its range, seasonal fluctuations or migration, timing of breeding and recruitment levels are important (Kingsford and Norman 2002). These basic parameters are vital for species conservation, pest management and striking the right balance in avoiding human–wildlife conflicts (Savard *et al*. 2000; Adams 2005), especially when the species in question is protected (Belant 1997). The Australian white ibis (*Threskiornis molucca*) is one such native species. In the urban environment, culling of eggs and adults has been implemented to reduce local populations for over a decade (Shaw 1999; Martin *et al*. 2007); however, our understanding of ibis ecology is limited.

Traditionally, large ibis populations occurred throughout the inland wetlands of eastern Australia (Carrick 1962; Cowling and Lowe 1981; Kingsford and Johnson 1998), typified by the Murray–Darling Basin (1 million km^2) which contains much of Australia's prime agricultural land and water storage (CSIRO 2008). This inland habitat has been degraded through drought and human encroachment, particularly damming, weirs, water extraction and diversion (Walker 1985; Kingsford 2000; Goss 2003; Kingsford *et al*. 2004; Buchanan 2009). Progressively over the past half century, human water management has decreased the frequency and magnitude of flooding events (Kingsford and Thomas 1995; Kingsford 2000; Buchanan 2009). Formerly, floods could occur at any time of year or location across a massive spatial scale (e.g. 2.69 million km^2, Roshier *et al*. 2001; Kingsford and Porter 2009), prompting waterbirds to travel hundreds of kilometres to breed in flooded wetlands at any time of year, and having multiple clutches when

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abundant resources and habitat are available (Frith 1959; Carrick 1962; Marchant and Higgins 1990; Roshier *et al*. 2001, 2008).

The populations of up to 50 taxa of wetland birds, including ibis, have been observed to decline over the last 25 years, based on annual aerial transect surveys of the wetlands of eastern Australia (Porter *et al*. 2006; Kingsford and Porter 2009). The annual ibis population shows considerable variability, with a peak count of 24 000 in 1986 and fewer than 3000 birds counted in the 9 years from 1998 to 2006 (Porter *et al*. 2006). This time period corresponds remarkably well with the observed increase of ibis populations in the Sydney region and along the east coast, although coastal monitoring is incomplete (Dixon and McGill 1979, 1989; Gosper 1981; Leach 1994; Keast 1995; Shaw 1999; Barrett *et al*. 2004).

Urban ibis are often managed in response to community or industry complaints, where their presence conflicts with human interests. Complaints predominantly result from colonial nesting (from 10 to >1000 birds), with issues such as noise, odour, faeces and eutrophication of water bodies commonly articulated. The concerns of industry predominantly relate to the risk of aircraft strikes (ATSB 2002; e.g. Blackwell *et al*. 2009). Primarily, control involves the removal of nests, eggs and habitat, or scaring birds from roosts, colonies and foraging sites (landfills or aerodromes, Shaw 1999; Ross 2004; Martin *et al*. 2007). For example, in the Gold Coast region of south-eastern Queensland, ibis management has been conducted since 1996; a breeding season maximum of 9600 eggs were removed in 1999 although the issues and control techniques remain and in 2008 the removal of 5500 eggs still occurred (Ecosure 2009). As a result of disturbance methods, ibis colonies have been observed to fragment and have reduced breeding effort (Shaw 1999); however, the long-term consequences of suppressed recruitment are poorly understood for this long-lived and widely dispersing species.

There is a lack of any long-term data on the ecology of ibis in the urban environment, although some short-term data exist. Urban ibis have been observed to travel up to 35 km to foraging sites (J. Martin, unpubl. data), have a modal clutch size of three eggs, a hatching success between 48% and 68% and fledging success between 28% and 66% (Lowe 1984; Beilharz 1988; Corben and Munro 2006; Murray and Shaw 2006). Despite the fact that ibis may have up to six clutches per season (mode = 2), a 5-year study found that, on average, ibis fledged only a single offspring per season (Beilharz 1988); however, the proportion of fledglings that survive to reproductive age is unknown. Studies of urban colonies report that the breeding season commonly commences in June and concludes as late as February (Lowe 1984; Kentish 1999; Murray and Shaw 2006; Martin *et al*. 2007), with seasonal and some latitudinal variation. At Healesville Sanctuary, a site with abundant nearby resources, ibis have shown the capacity for year-round nesting, with low numbers of nests recorded from February to June in the 1984 'non-breeding' season (Beilharz 1988). Despite this ecological information, the majority of urban colonies lack good detailed population monitoring.

Given the decline in inland populations, it is important to understand the consequences of urban management for ibis and any implications for the overall population. The present study of ibis in the Sydney region aims to (1) establish the abundance of the population during the breeding and non-breeding seasons, (2) determine whether the population is increasing, and (3) identify the importance of different foraging and roosting sites. The data we present provide the first quantitative baseline information for ibis management within the Sydney region.

Methods

Regional population surveys

The location of ibis foraging, roosting and breeding sites across the Sydney region has been collated annually by the National Parks and Wildlife Service (NPWS) through a community survey conducted in December since 2003 (G. Ross, pers. comm.). Sites identified from these data provided the basis of our regional monitoring, to which additional sites were added as they were colonised. We surveyed 54 discrete sites, which included the largest foraging and breeding sites as well as smaller sites (for site locations see Appendix 1). The 54 sites were grouped into 15 areas, consisting of five landfills and 10 suburbs containing multiple smaller sites. All areas were surveyed for 2.5 years. For the period from June 2006 to September 2007, surveys were conducted fortnightly; however, from October 2007 until January 2009 4-weekly surveys were conducted.

Regional surveys were conducted over three consecutive days to census populations within a discrete period to avoid duplicate counting. At all sites, we recorded the number of adults, juveniles and nestlings. Juvenile ibis were distinguishable by their feathered heads, which recede to a neck-collar as they reach sexual maturity (2.5–3 years, Beilharz 1988). Birds were considered to be nestlings for as long as they were observed being fed by adult ibis. From March 2007, we also recorded the number of nests containing eggs, nestlings or being incubated by adults. All counts were facilitated by the use of binoculars and telescopes.

Data analyses

There were two main categories of sites used by ibis, namely landfill sites (used for foraging) and colony sites (used for roosting, nesting and sometimes foraging). To simplify the analysis of the 54 survey sites, we analysed the 15 areas (5 landfills and 10 suburbs) separately, including the two major colonies of Lake Gillawarna and Lake Annan as individual suburbs. To identify variation in population size associated with breeding, the months of July to December were grouped as the breeding season and January to June the non-breeding season. The following two categories of breeding sites were identified: 'urban-natural', defined as islands within a pond in an urban park; and 'urban-built', defined as street trees, predominantly palms (*Phoenix canariensis*), in suburban and industrial areas. The amount of nesting observed within both habitats was compared with a two-factor analysis of variance (ANOVA) for the 2007 and 2008 breeding seasons and a single-factor ANOVA for the 2008 non-breeding season.

Three-factor ANOVA was used to determine whether there were differences in population size associated with season (breeding or non-breeding), year (2007 or 2008) or habitat (landfill or colony). Separate tests were used to analyse adult and juvenile responses. Because the population survey included three breeding seasons and only two non-breeding seasons, the breeding season data for 2006 was not included in the three-factor analyses. To determine whether the landfill adult population is an adequate indicator of the regional population, we investigated the correlation between the number of adult birds recorded at landfills and those at colonies. We were interested in evaluating whether surveys of landfills could be used as a surrogate for assessing the regional population. For all analyses, monthly data was used, and where more than one count was conducted within a month (e.g. fortnightly surveys) we used the monthly average.

Variation in the number of nestlings produced between seasons and years was analysed with a two-factor ANOVA. Single-factor ANOVAs were used to compare the number of active nests present between breeding and non-breeding seasons in 2008, and to compare the number of active nests present between the 2007 and 2008 breeding seasons. All data were tested for homogeneity with Cochran's test and where necessary were log(x+1) transformed to stabilise variances. Significant interactions were assessed with Tukey's pairwise comparisons.

Results

Regional population

The ibis population in the Sydney region was observed to more than double between the 2006 and 2008 breeding seasons, with total peak counts of 4200 and 8900 respectively. The peak adult population increased by 69% between the 2006 and 2007 breeding seasons, and a further 24% between the 2007 and 2008 seasons (Fig. 1). Increases were also observed within the peak juvenile population, with a 140% increase between the 2006 and 2007 breeding seasons, and 31% between the 2007 and 2008 breeding seasons. However, although there was a 76% increase in the peak number of nestlings between the 2006 and 2007 breeding seasons, there was a 24% decline in peak nestling numbers between 2007 and 2008 (Fig. 1). The observed increase in the regional ibis population occurred across almost all survey areas (Table 1). In addition, there was a significant correlation between the adult population at landfill and colony habitats ($r = 0.70$, $t_{62} = 5.39$, $P < 0.001$, Fig. 2). However, the low r-value (0.70) indicates that surveying only landfills would be a poor predictor of the colony adult population, such that surveys of both habitats are required for a good measure of the regional population.

Across the Sydney region the majority of both landfill and colony sites followed cyclical growth trends, supporting larger adult populations in the breeding season (Table 1). The exception was Eastern Creek landfill, which apart from a small non-significant seasonal decline in the 2007 non-breeding season was observed to support continuous growth and attracted three times as many adult ibis during the 2008 breeding season as did the second largest landfill (Lucas Heights, Fig. 3). As with the variable size of landfill populations, colony areas supported dramatically different numbers of adult birds. The two largest colonies occurred on islands at Lake Gillawarna and Lake Annan (Fig. 4*a*) and were roughly twice the size of all other colony areas, despite continued growth within nearby areas (e.g. Homebush and Rockdale, Fig. 4*b*).

The colony habitats across the Sydney region supported nesting in both 'urban-natural' and 'urban-built' (e.g. street tree) habitats. The amount of nesting within each of the two habitats differed significantly ($F_{1,20} = 33.45$, $P \leq 0.001$); however, within both habitats nesting was consistent over the two breeding seasons ($F_{1,20} = 1.21$, $P = 0.29$). On average, 80% of the adult population within colonies was observed at urban-natural habitats (e.g. wetlands and parks), which on average supported 69% of nests (Fig. 5). Although there were many more colonies in the urban-built habitats (76% of all colonies, $n = 49$), they were much smaller, comprising only 20% of the adult population.

Population variability

The variation in the number of adult ibis within the two habitats (landfill or colony) was not dependent on season (breeding or non-breeding) and year (2007 or 2008) (three-way interaction, $F_{1,40} = 1.7$, $P = 0.19$). Variation in adult numbers between years was dependent on habitat ($F_{1,40} = 5.8$, $P = 0.02$); specifically, the number of birds at landfills in 2008 was considerably larger than

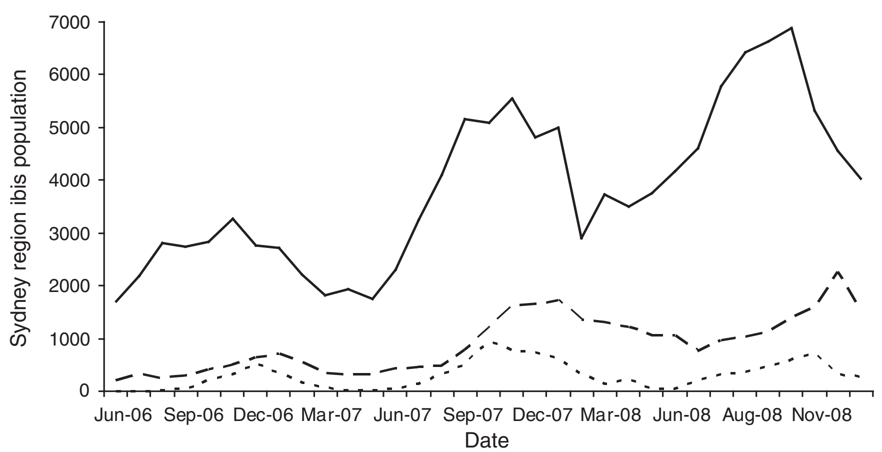

Fig. 1. Australian white ibis population in the Sydney region by age class: adults (solid line), juveniles (dash) and nestlings (dots) across three breeding seasons (July–December) and two non-breeding seasons (January–June). Regional surveys were conducted over three consecutive days.

Table 1. The mean (±s.e.) adult population observed during the breeding (July to Dec.) and non-breeding (Jan. to June) season within each landfill or colony area across the Sydney region

Surveys were conducted at a monthly frequency as a minimum

Year	2006	2007		2008	
Season	Breeding	Non-breeding	Breeding	Non-breeding	Breeding
Landfill					
Belrose	236 (17)	76 (19)	227 (32)	128 (38)	150 (19)
Eastern Creek	758 (44)	701 (55)	851 (44)	1537 (161)	2096 (97)
Jacks Gully[A]	152 (32)	172 (15)	379 (31)	399 (29)	90 (17)
Lucas Heights	226 (45)	42 (19)	301 (52)	122 (35)	606 (25)
Panania	179 (19)	238 (31)	153 (12)	183 (22)	118 (12)
Colony area					
Rockdale	23 (4)	40 (8)	49 (12)	48 (11)	182 (21)
Botany	42 (8)	17 (3)	59 (8)	44 (6)	92 (11)
Featherdale Wildlife Pk[B]	37 (7)	66 (5)	59 (5)	66 (8)	47 (4)
Lakemba	28 (6)	52 (4)	90 (4)	57 (6)	83 (6)
Marrickville[B]	35 (9)	51 (11)	190 (15)	38 (10)	82 (12)
Homebush[B]	99 (17)	93 (20)	182 (14)	107 (10)	338 (39)
Centennial Pk	197 (19)	209 (13)	213 (13)	215 (18)	260 (14)
City[B]	176 (16)	88 (8)	274 (30)	157 (15)	265 (23)
Lake Annan	80 (9)	123 (17)	564 (56)	530 (38)	578 (104)
Lake Gillawarna	311 (49)	69 (24)	886 (101)	307 (89)	928 (109)

[A]Jacks Gully stopped receiving putrescible waste in July 2008, replaced with an internal facility.
[B]Colonies where nest and egg or habitat removal was undertaken.

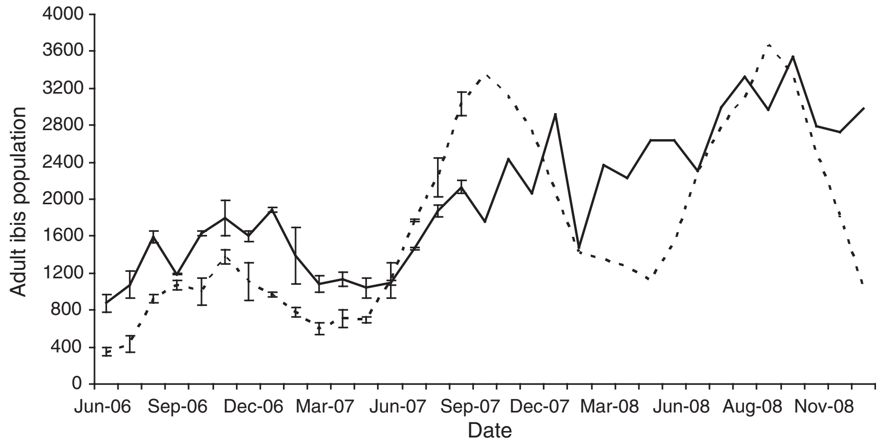

Fig. 2. The number of adult ibis recorded in the Sydney region at landfills (solid line) and colonies (dots) across three breeding and two non-breeding seasons. Months with greater than one survey are presented as an average (±s.e.).

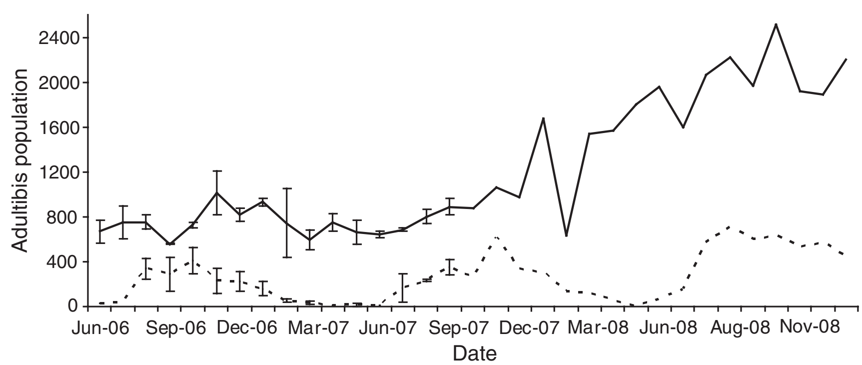

Fig. 3. Monthly variation in the number of adult ibis foraging at the two largest landfills in the Sydney region: Eastern Creek (solid line) and Lucas Heights (dash). Months with greater than one survey are presented as an average (±s.e.).

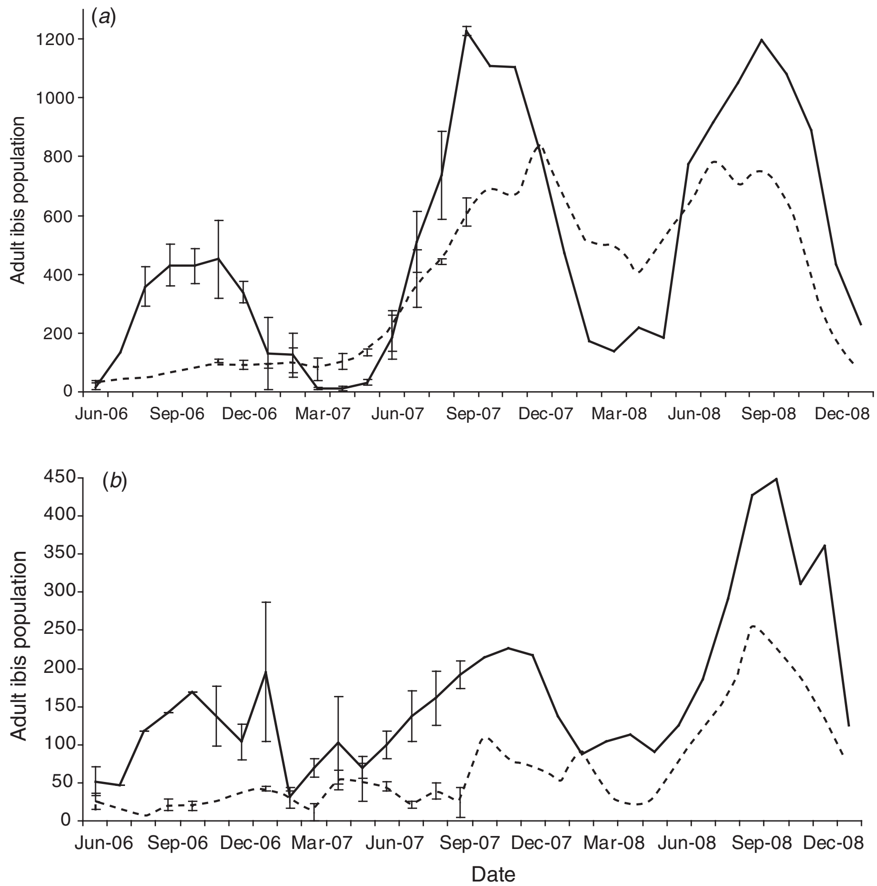

Fig. 4. Monthly variation in the number of adult ibis recorded at (*a*) the two largest colonies in the Sydney region, i.e. Lake Gillawarna (solid line) and Lake Annan (dash), and (*b*) colonies where substantial population growth occurred, i.e. Homebush region (solid line) and Rockdale region (dash). Months with greater than one survey are presented as an average (±s.e.).

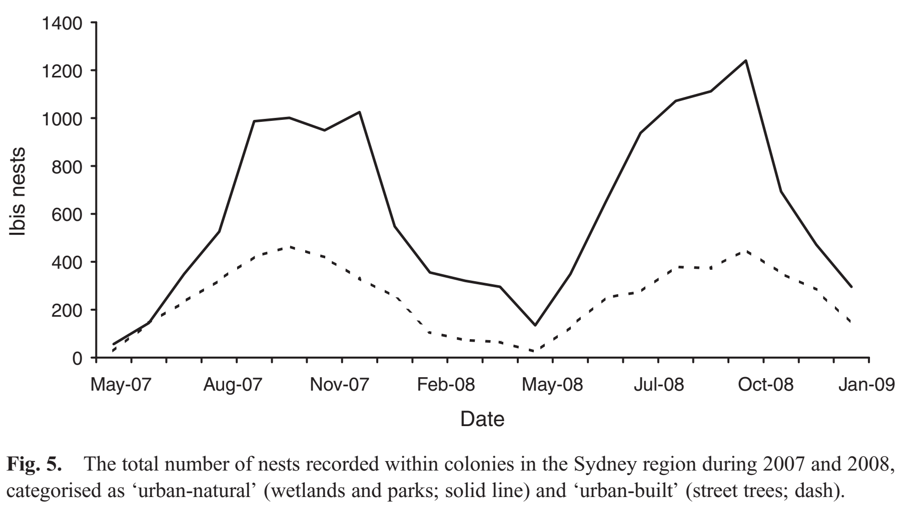

Fig. 5. The total number of nests recorded within colonies in the Sydney region during 2007 and 2008, categorised as 'urban-natural' (wetlands and parks; solid line) and 'urban-built' (street trees; dash).

at colonies in 2008 and within both habitats in 2007 (Tukey's pairwise, $P = 0.042$, Table 2*A*). In addition, the number of birds within colony habitats in 2007 and 2008 was almost significantly different (Tukey's pairwise, $P = 0.055$, Table 2*A*). Adult variation at both habitats was seasonally dependent ($F_{1,40} = 11.0$, $P = 0.002$). The regional population was larger during the breeding season than the non-breeding season (Tukey's pairwise, $P = 0.002$, Table 2*A*), and during the non-breeding

Table 2. Mean (±s.e.) number of (a) adult and (b) juvenile ibis counted per month, presented in categories for which significant interactions were identified from ANOVA and Tukey's post-hoc tests

Means identified by the same letter were not significantly different ($P > 0.05$)

A	Season/Habitat	Landfill	Colony
	2007	1637 (136)[b]	1756 (305)[b]
	2008	2729 (159)[a]	2232 (241)[b]
	Non-breeding	1832 (197)[b]	1220 (149)[a]
	Breeding	2534 (192)[c]	2768 (174)[c]

B	Year	2007	2008
	Non-breeding	197 (22)[a]	620 (80)[b]
	Breeding	516 (102)[b]	697 (80)[b]

Table 3. Seasonal mean (±s.e.) number of nests per area from monthly surveys conducted during the breeding (July–December) and non-breeding (January–June) seasons

Area	2007	2008	
	Breeding	Non-breeding	Breeding
Rockdale	23 (7)	9 (5)	103 (14)
Botany	28 (4)	7 (3)	26 (3)
Featherdale, Wildlife Park	20 (3)[A]	10 (4)[A]	14 (2)[A]
Lakemba	41 (2)	19 (4)	31 (3)
Marrickville	90 (9)	19 (8)[A]	46 (3)
Homebush	81 (9)[A]	31 (7)[A]	127 (23)[A]
Centennial Park	45 (9)	20 (6)	63 (7)
City	88 (11)[A]	37 (13)[A]	105 (8)[A]
Lake Annan	259 (34)	232 (27)	325 (68)
Lake Gillawarna	408 (62)	117 (45)	425 (44)

[A]Colonies where nest and egg or habitat removal was undertaken.

season more birds were observed at landfills than at colonies (Tukey's pairwise, $P = 0.008$, Table 2*A*). There was no significant interaction between year and season ($F_{1,40} = 1.19$, $P = 0.28$).

Juvenile ibis showed a similar seasonal pattern to that of the adults over both years. The annual (2007 or 2008) variation in the juvenile population was not dependent on habitat (landfill or colony) and season (breeding or non-breeding) (three-way interaction, $F_{1,40} = 2.16$, $P = 0.15$). Significantly fewer juvenile birds were observed during the 2007 non-breeding season than in the 2007 breeding and 2008 breeding and non-breeding seasons ($F_{1,40} = 7.4$, $P = 0.01$, Tukey's pairwise, $P < 0.001$, Fig. 1, Table 2*B*). The number of juveniles fluctuated cyclically within both habitats (landfill and colony) as expected; however, there was no significant habitat and year interaction ($F_{1,40} = 0.6$, $P = 0.44$) nor habitat and season interaction ($F_{1,40} = 1.2$, $P = 0.28$). This was most likely because of the continued low level of breeding which occurred during the 2008 'non-breeding' season which sustained a higher than expected juvenile population (Fig. 1).

The numbers of nestlings produced did not vary with year or season ($F_{1,20} = 2.27$, $P = 0.15$), despite the larger adult population throughout 2008. As expected, fewer nestlings were produced in the non-breeding than the breeding season ($F_{1,20} = 7.97$, $P = 0.01$). However, the overall nestling population was comparable in both 2007 and 2008 ($F_{1,20} = 1.31$, $P = 0.27$) despite the higher peak count in 2007 than in 2008. Similarly, the mean number of nests in the 2007 and 2008 breeding seasons did not change ($F_{1,10} = 0.43$, $P = 0.52$). As expected, there was a significant difference between the number of nests counted during the breeding and non-breeding seasons in 2008 ($F_{1,10} = 34.7$, $P = <0.001$), despite the high level of nesting observed during the non-breeding season predominantly at urban-natural compared with urban-built colonies ($F_{1,10} = 12.47$, $P = 0.005$, Table 3, Fig. 5).

Discussion

Regional population growth

The total ibis population of the Sydney region was observed to almost double between the 2006 and 2007 breeding seasons and there was a further increase during 2008. In 2006, the peak breeding season count for all ages was 4200, which at the time was considered a high count for the Sydney region on the basis of the three annual community surveys coordinated by the NPWS since 2003 (G. Ross, pers. comm.). The regional increase over the next 2 years was so substantial that the minimum 2008 non-breeding adult population (2900) was almost as large as the 2006 peak adult breeding population (3300).

Sustained population increases in the breeding season imply that the Sydney region is an important breeding habitat for ibis in the eastern states. The island habitats of Lake Gillawarna and Lake Annan supported the largest colonies and both were located within 100 m of residential housing, which generated complaints from the local residents. Both colonies occurred on constructed islands within stormwater retention basins, which provide refuge from humans and land predators (e.g. fox (*Vulpes vulpes*), dog (*Canis familiaris*), cat (*Felis catus*)), and both are located within 5 km of a landfill. It is interesting to note that these habitats have only recently been colonised by ibis. Nesting was first observed at Lake Annan in 2005 (S. Hannan, pers. comm.), and at Lake Gillawarna, counts of only tens of ibis (<200) were made between 1997 and 2002 (D. McKay, pers. comm.), with no breeding before approximately the year 2000. This means that the local human populace was unaware of ibis conservation issues (e.g. inland habitat degradation), with the consequence that when the local numbers increased and issues emerged (noise, odour), they believed that ibis should be controlled. This belief was compounded by the misconception that the recent arrivals were the exotic African sacred ibis (*T. aethiopicus*), warranting control as an introduced species.

The population growth over the study period was particularly observable at one landfill, Eastern Creek, where consistent mean monthly population counts in 2006 and 2007 (mean = 758 and 765, respectively) were observed to more than double in 2008 (mean = 1824, Table 1, Fig. 3). The 2008 increase was associated with a change in waste disposal methods which increased the surface area of available food. Two excavated pits (300 × 160 × 15 m) were sequentially filled and refuse was covered throughout, and at the end of each day, with contaminated recycling ('oversised digested organics and bulky materials shredded and composted', J. White, pers. comm.) rather than the 15 cm of soil that was used conventionally (Environment Protection Authority 1996). Similar observations of increases in gull populations have been observed where refuse has been readily available (Coulson *et al*. 1987).

The regional ibis population was highly variable both between years and seasons, and further monitoring is required to improve our understanding of the population and its habitat use. One option to reduce the cost of regional monitoring is to routinely survey only the landfill sites; however, our data demonstrated that this does not provide an adequate approximation for the regional population. Seasonal declines during each non-breeding season were greater at colonies than at landfills, reflecting a change in the use of colony sites. Thus, although landfills and colonies both showed seasonal fluctuations, there were differences in the patterns of temporal usage, which result in a relatively poor correlation between the two habitats at some times of year.

Population variability: seasonal movements

The ibis population increased dramatically over the three breeding seasons but was observed to decline substantially during the non-breeding seasons (Fig. 1). Specifically, the number of ibis within all three age groups and the number of nests were significantly higher in the breeding than in the non-breeding seasons. As expected, during the non-breeding season the number of ibis at colony sites declined. Also landfill counts declined seasonally, although to a lesser extent than colonies, because some colony birds shifted to landfill sites as was observed during a radio-tracking study of urban ibis (J. Martin, unpubl. data).

Despite the overall increase throughout the study, our data clearly showed seasonal fluctuations of ibis adults and juveniles between the breeding and non-breeding seasons indicating that some birds migrate into the Sydney region to breed. This has implications for local land managers and ibis conservation, because management of the urban population will have an impact on the population beyond the Sydney region. For example, a nestling banded in Sydney was observed in Townsville (1687 km from Sydney), northern Queensland, 7 months after banding and numerous movements of several hundred kilometres have been reported (Carrick 1962; Ross and Legoe 2006; Smith 2009).

Long-distance dispersal may have significant implications if urban breeding habitats are acting as the primary recruitment centres for the ibis population of the eastern states. It is likely that urban breeding constitutes the majority of the current annual reproduction, as natural breeding within flooded wetlands has been limited during the past decade (Porter *et al*. 2006; Kingsford and Porter 2009). An additional behaviour that may have a bearing on the natural and urban population is that of natal philopatry. A low level of natal philopatry has been observed in ibis, with some adult birds (+3 years) returning to breed at their natal colony (Lowe 1984).

Natal philopatry has also been observed within the Sydney region (J. Martin unpubl. data), yet the growth of the regional population was unlikely to be the sole result of local recruitment. The doubling of the adult population over 3 years was too large an increase to be caused by local recruitment because nestling production in the 3 years preceding our study was likely to be comparable to the low level observed in the 2006 breeding season (G. Ross, pers. comm.). Thus, without comparable natural alternatives, the habitat and foraging resources within the urban environment appear to be highly attractive to the broader ibis population, especially for reproduction.

Anthropogenic foraging resources (landfills) and management

Food availability is a fundamental issue controlling nuisance bird populations (Thomas 1972; Smith and Carlile 1993; Belant 1997; Frederiksen *et al*. 2001), and landfills are an important food source for species including ibis and gulls (Migot 1992; Belant *et al*. 1998; Duhem *et al*. 2003; Ramos *et al*. 2009; J. Martin, unpubl. data). The percentage of adult ibis counted in surveys at Sydney landfills ranged between 26 and 66%, averaging 44% of monthly regional counts (Fig. 2). Comparatively, in south-eastern Queensland, 70% of the ibis population was observed foraging at landfills (Shaw 1998). A radio-tracking study conducted in the Sydney region located 85% of the ibis population ($n = 82$) foraging at a landfill, with some birds recorded making multiple trips from colonies to landfills throughout the day (J. Martin, unpubl. data). Studies of gulls have reported the actual foraging population to be up to seven times the observed population on a given day (Coulson *et al*. 1987; Belant *et al*. 1998). Therefore, it is likely that an even larger proportion of the ibis population in the Sydney region exploits landfill foraging resources than what was indicated by our surveys.

Use of landfills by an increasing population of ibis has both immediate and long-term consequences. An extension of the breeding season as a result of abundant food supplies will not only increase ibis populations, but is likely to increase human–wildlife conflicts. Extended breeding has been previously reported for human commensal species (Rollinson and Jones 2002; Partecke *et al*. 2005; Small *et al*. 2005), and multi-brooded species, such as ibis (Lowe 1984), have been documented to commence breeding earlier than single- or double-brooding species when supplied with additional resources (Svensson 1995). As urban nesting is the most common cause of human–ibis conflict, any extension of the breeding season is likely to increase community complaints. For example, the Lake Annan colony supported a large breeding population, with a minimum of 100 nests and 370 adults over a 19-month period (Fig. 4*a*). This high level of breeding sustained the issues that human residents dislike the most, i.e. noise and odour (from faeces, carcasses, unviable eggs), and generated considerable complaints from the local residents.

Additional concerns have been raised regarding interspecific competition (e.g. for habitat) and the potential for predation of threatened species, as has been observed for gulls (Skórka *et al*. 2005; Ramos *et al*. 2009) and sacred ibis in South Africa and Europe (Kopij 1999; Clergeau and Yésou 2006; Williams and Ward 2006). For example, concerns have been raised that ibis may be having a negative impact on the grey-headed flying-fox (*Pteropus poliocephalus*), a listed threatened species, by defoliating shared roost sites and altering the micro-climate which is crucial for preventing heat stress within flying-fox colonies (Department of Environment and Climate Change NSW 2007). No studies have quantified the impacts due to ibis within shared colonies; however, it is possible that such defoliation is caused by the flying-foxes themselves, because they are well known to damage canopies, sometimes resulting in tree death (Pallin 2000; Fakes 2005).

The human–wildlife conflicts and potential impacts on other wildlife are likely to intensify if urban ibis populations become permanent as a result of the loss of traditional habitat. Improving current environmental flows and increasing wetland habitat conservation across inland eastern Australia (Kingsford and Norman 2002) will be essential to provide an alternative habitat for ibis. Importantly, a major attraction and resource within urban areas, i.e. landfills, are gradually being converted to internal facilities for energy generation (Duhem *et al*. 2003; see also European Union declaration: 1999/31/EC and 2003/33/EC). The resulting reduction in available food may also decrease the number of clutches individual ibis have in a season, which may reduce the observed extended breeding season, pleasing the affected human population. Such actions are likely to be detrimental to ibis populations across the eastern states, not just within the Sydney region.

Integrated management of ibis is clearly required in which the relationships between food availability and breeding habitat are considered at a regional scale, rather than focussing on the local management of breeding colonies as is currently practiced. Destruction of nests, eggs and nesting habitat are likely to result in colony fragmentation and relocation, which may shift the problem elsewhere, depending on the scale of relocation (Bosch *et al*. 2000). As long as the natural population remains small, breeding in urban centres will be important for this long-lived species (up to 26 years). Urban conflicts need to be resolved with human education and a conservation agenda, preferably with the provision of refuge habitat where birds are not disturbed.

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Appendix 1. Sites surveyed within the Sydney region for Australian white ibis

Site	Latitude	Longitude
Auburn, Station St	33.8416	151.041
Belrose landfill	33.7151	151.210
Blacktown, Nurragingy Park	33.7641	150.861
Botany Wetlands	33.9439	151.191
Botany, Hale St	33.9471	151.196
Botany, Sir Joseph Banks Park	33.9563	151.201
Botany, St Mathews Church	33.9411	151.195
Burwood Park	33.8729	151.104
Cabramatta Ck	33.9052	150.941
Canada Bay, Queen Elizabeth Park	33.8635	151.102
Caringbah, Camillia Gardens	34.0430	151.112
Centennial Park	33.9005	151.232
Eastern Ck, Chandos Rd	33.8336	150.869
Eastern Ck, Redmayne Rd	33.8379	150.861
Eastern Ck landfill	33.8113	150.868
Eastern Ck, farm dams	33.8041	150.863
Featherdale Wildlife Park	33.7660	150.884
Granville, FS Garside Park	33.8318	151.015
Granville, Good St 140	33.8240	151.013
Granville, Memorial Park	33.8347	151.014
Hen and Chicken Bay	33.8617	151.128
Homebush, Bicentennial Park	33.8505	151.078
Homebush, Birnie Avenue	33.8526	151.064
Hurstville Council depot	33.9688	151.063
Jacks Gully landfill	34.0746	150.746
Lake Annan	34.0550	150.760
Lake Gillawarna	33.9062	150.981
Lakemba Station	33.9204	151.076
Lakemba, Chalmers St	33.9222	151.090
Lakemba, Reginalde St	33.9213	151.092
Lakemba, Wiley Park	33.9266	151.073
Lucas Heights landfill	34.0437	150.969
Malabar, Franklin Rd	33.9627	151.235
Marrickville Rd	33.9094	151.153
Marrickville, Carrington Rd	33.9178	151.157
Marrickville, Dibble waterhole	33.9142	151.140
Taren Point, Gwawley Park	34.0226	151.121
Monterey, Barton Park	33.9732	151.143
Panania landfill	33.9474	150.987
Punchbowl Station	33.8931	151.055
Randwick, Heffron Park	33.9507	151.233
Randwick, TAFE	33.9055	151.232
Rockdale, Bicentennial Park	33.9619	151.147
Royal Botanic Gardens	33.8645	151.217
Ryde, Victoria Rd	33.8174	151.112
Silverwater, Reading Cinema	33.8484	151.047
Sydney Park	33.9105	151.185
Sydney, Belmore Park	33.8819	151.207
Sydney, Cook and Phillip Park	33.8729	151.214
Sydney, Darling Harbour	33.8748	151.201
Sydney, Domain	33.8683	151.215
Sydney, Hyde Park	33.8729	151.211
Sydney, Macquarie St	33.8886	150.786
Woodcroft Wetland	33.7528	150.879