Corella, 2008, 32(3/4): 58-65

THE ABUNDANCE AND MOVEMENTS OF THE AUSTRALIAN WHITE IBIS *Threskiornis molucca* IN AN URBAN ENVIRONMENT

DANIEL T. CORBEN and URSULA MUNRO[1]

Department of Environmental Sciences, University of Technology, Sydney, PO Box 123, Broadway, NSW 2007, Australia.
[1]Corresponding author. E-mail: Ursula.Munro@uts.edu.au

Received: 31 May 2007

The Australian White Ibis *Threskiornis molucca* has established large, permanent populations in many urbanised areas of coastal eastern Australia, and many agencies aim to reduce its numbers. This study investigates daily and seasonal trends in the abundance and movements of ibis in Centennial Park (a large inner-city park of Sydney, NSW) from autumn to mid-winter (non-breeding to breeding season). Abundances fluctuated daily and seasonally. Highest numbers of ibis were observed during early mornings and evenings, while numbers were lowest during late morning and midday. Most ibis travel daily to a feeding site and only used the park for roosting. Ibis movements into and out of the study area were significantly orientated toward the same main direction throughout the study. Key temporal trends in ibis movements to and from the roost were identified, with approximately 50 per cent of all morning departures occurring within 40 minutes of first light and over 50 per cent of all evening arrivals occurring between 40 and 10 minutes before darkness. Abundances also fluctuated seasonally with lowest numbers recorded during March (autumn) and highest numbers recorded during July (mid winter, start of breeding period). The ibis population of Centennial Park, and possibly the entire Sydney ibis population, may consist of a permanently present, sedentary subpopulation as well as a mobile subpopulation that spends the non-breeding period outside Sydney and migrates to Sydney for the breeding period. This is consistent with knowledge on ibis colonies throughout Sydney and other urban areas along the east coast of Australia.

INTRODUCTION

The Australian White Ibis *Threskiornis molucca* (hereafter referred to as ibis) is a native bird, which occurs throughout most of Australia except the arid interior. Its range extends to southern New Guinea and Pacific islands such as the Moluccas and Solomons (Purchase 1976; Marchant and Higgins 1990; Hancock *et al.* 1992). Natural habitats for ibis include freshwater wetlands and sheltered marine environments such as intertidal mudflats, estuaries and mangrove wetlands (Marchant and Higgins 1990). The ibis has greatly benefited from human settlement (Lowe 1999) and can now be found in many urban environments e.g. parks, picnic grounds, garbage tips and landfill sites (Marchant and Higgins 1990; Hancock *et al.* 1992; Lowe 1999; Perry 2001; Ross 2004). It has dramatically increased its range and population size in Australia since the 1950s, mainly due to increased irrigated agriculture expanding its foraging and breeding habitat (Blakers *et al.* 1984; Marchant and Higgins 1990). Its behavioural plasticity, flexibility in habitat selection and tolerance to humans has led to permanent and/or highly abundant populations in many urban areas, including areas where the ibis was once absent or uncommon (Bekle 1982; Ross 2004; Shaw and Murray 2004). In the Sydney region ibis were absent or uncommon prior to 1950 and found only in the tidal areas of Botany Bay and the Hawkesbury Marshes (Morris 1983). Ibis presence was unpredictable between 1950 and 1980, with numbers fluctuating from zero to several hundred (Morris 1983). In urban environments ibis will frequently roost and breed communally and predominantly nest close to water bodies (Cowling and Lowe 1981; Marchant and Higgins 1990; Perry 2001). They commence breeding when approximately three years old (Marchant and Higgins 1990). The first breeding record for ibis in the Sydney region was in 1982 (Morris 1983). Ibis are now permanently present in many open spaces (e.g. Centennial Park, Royal Botanical Gardens) throughout the Sydney region, and form large breeding colonies annually (Roberts 1993). Equivalent increases in abundances and range expansions into coastal urbanized areas have been observed in other cities of eastern Australia (e.g. Melbourne, Brisbane, Gold Coast (Lowe 1999; Shaw and Murray 2004)). A greater abundance of food resources along with their ability to exploit human refuse appear to be factors contributing to the success of ibis in urban environments in coastal eastern Australia (Ross 2004; Shaw and Murray 2004; Corben and Munro 2006). Similarly in Europe, introductions of the closely related Sacred Ibis *T. aethiopicus* of Africa have led to populations that are quickly growing, spreading and reaching pest status (Clergeau and Yésou 2006).

The increased abundance of the ibis in urban areas has ecological and social impacts and the species is regarded as a pest due to ibis: (1) destroying environments through damaging and killing vegetation, and polluting and fouling water bodies (Kentish 1994, 1999; Shaw and Murray 2004); (2) competing with and killing native wildlife (Bekle 1982); (3) carrying and transmitting diseases potentially dangerous to humans and animals (e.g. avian influenza, *Salmonella* and Newcastle disease) (Ross 2004; Epstein *et al.* 2007); (4) colliding with aircraft, threatening aircraft and passenger safety (Australian Transport Safety Bureau 2002); and (5) scavenging from bins, dispersing litter, and harassing and stealing food from people (Hancock *et al.* 1992; Lowe 1999; Ross 2004). As a result, humans commonly have negative attitudes toward ibis in urban areas and demand immediate action to manage this species (Meyer-Gleaves 2003). Ibis management includes egg and nest removal, trapping and culling, scaring, dispersing ibis from roosts and landfills, habitat modification and public education (Ross 2004; Shaw and Murray 2004). Nothing is known about the impacts or effectiveness of this management on ibis populations. Since the ibis is native, it is important that management does not negatively impact on the species at larger scales. Primarily, it is the lack of knowledge on the species' general biology, ecology and population dynamics, especially in urban environments, that has made management and its assessment difficult.

Most literature on ibis is incorporated into general studies on waterbird species (e.g. Gosper 1981; Morton *et al.* 1993; Kingsford and Johnson 1998; Briggs and Thornton 1999) and limited studies on ibis in their natural habitats (Marchant and Higgins 1990). Specific studies focusing on ibis are lacking. In urban environments detailed research is rare (Corben and Munro 2006). The aim of this study is to provide information on the biology and ecology of ibis in an urban environment for scientifically based management. Specifically, we aim to determine if ibis display daily or seasonal changes (autumn to mid winter; non-breeding to breeding season) in their abundances and movements in an urban environment (Centennial Park, Sydney).

METHODS

Study site

Centennial Park is a large urban park (360 hectares) located approximately five kilometres southeast of Sydney's central business district and seven kilometres northeast of its international airport. The park contains large open spaces, ornamental gardens, patches of remnant vegetation, and five major ponds with 12 generally equal sized islands (approximately 464 –1 590 m^2). During our study all islands contained varying degrees of herbaceous ground cover (5 – 70%) and a canopy (10 – 40 m) of native and exotic trees and shrubs. The park is a major roosting and breeding site for ibis in Sydney and is representative of other areas with ibis problems in eastern coastal Australia (G. Ross, pers. comm.).

Data collection and analysis

The study took place between 17 March and 31 July 2003. Abundances and movements of ibis in and out of the park were recorded once per week.

Abundances

Ibis occurred predominantly on the islands and were rarely seen elsewhere in the park; therefore we only recorded the number of ibis on each of the 12 islands. Although adults and immature birds were distinguished using plumage characteristics (Marchant and Higgins 1990), immature ibis were rare (233 of 14 614 observations; 1.6%) throughout the study so we pooled data sets, focusing on overall abundances of ibis in the park. Each sampling day was divided into four two-hour sampling periods (i.e. early morning, late morning, midday and evening). Early morning sampling began at first light (approximately 0530 hours in March, 0600 hours in July); late morning sampling started two hours after first light; midday sampling commenced at 1200 hours; while evening sampling started two hours before total darkness. During each sampling period, the sampling order of the islands was randomised to avoid potential bias that may arise from sampling the islands in the same sequence. Environmental variables (i.e. weather, cloud cover, temperature) were randomised within the experimental design.

Ibis counts from each island were summed to calculate the total number (abundance) of ibis in the park during each sampling period for each sampling day. A two-factor general linear model analysis of variance (GLM ANOVA) combined with Tukey's pairwise comparisons (TPC) (Zar 1996) was performed on total ibis abundances using the orthogonal factors sampling period (early and late morning, midday, evening) and month (March to July) to detect daily and seasonal differences in ibis abundances. We also calculated mean total abundances (± SE) for each sampling period and month.

Movements

Ibis movements were observed from a small hill between two large ponds. This location gave the best and least obstructed view of Centennial Park and its surrounding skyline. The hill was within 100 m of several major ibis roosting sites. Observations took place once per week during the morning, midday, and evening. Morning sampling began roughly 10 minutes before first light in the sky (approximately 0530 hours in March, 0600 hours in July) and ended two hours after first light (total sampling time = 130 min). Midday sampling took place from 1200 to 1300 hours (total sampling time = 60 min). Evening sampling included the two hours before and 10 minutes after total darkness (approximately 0630 hours in March, 0545 hours in July) (total sampling time = 130 min). Each sampling period was divided into 10-minute intervals, during which ibis flying into or out of the park were counted using Zeiss binoculars (10 x 40 magnification). We were able to identify ibis in flight within a distance of up to approximately five kilometres (estimated from geographical reference points). The circular area surrounding the observation point was divided into 12 equal sectors of 30 degrees with the midpoint of the first sector pointing to 0 degrees (magnetic north). During each 10-minute interval, the numbers of ibis arriving (flying into) and departing (flying out of) Centennial Park in any of these sectors were recorded. Local movements (i.e. birds that did not leave or enter the park) were not included.

We calculated the total number of ibis arriving into or departing from the park for each sampling period. We standardized our data by dividing the total number of ibis recorded during each sampling period by the number of minutes sampled (i.e. 130 min for morning and evening sampling, and 60 min for midday sampling), and then calculated from these values the total numbers of arriving or departing ibis per hour sampled for each sampling period and month. A three factor GLM ANOVA was then performed using the orthogonal factors movement type (arrival or departure), sampling period (morning, midday, evening) and month (March to July) to detect differences between the numbers of arriving and departing ibis and among sampling periods and months.

Morning departures and evening arrivals of ibis were further analysed to identify the times during these sampling periods when movements were most frequent. Data were first standardized by calculating the percentages of departing or arriving ibis for each 10-minute time interval from the total number of departing or arriving ibis during each sampling period.

A two factor GLM ANOVA was performed on the square root transformed data using the orthogonal factors time interval and month to identify differences between ibis movements throughout each sampling period and among months. We also investigated whether the directions of these movements were randomly distributed or significantly oriented into one direction. From the total number of ibis arriving into (for evening arrivals) or departing from (for morning departures) each of the twelve 30 degree sectors, we calculated a mean arrival and departure direction (α_m) and its vector (r_m) for each sample day (Batschelet 1981). A second order mean departure and arrival angle (α_n) and vector (r_n) were then calculated from the mean departure and arrival directions (α_m) of all sampling days. To determine whether ibis movements were significantly oriented on each sampling day and throughout the entire study period, first and second order means were tested against randomness with the Rayleigh test (Batschelet 1981).

All linear statistical analyses were conducted using the Minitab software package (Version 13.1; Minitab Inc., USA). None of the data sets were normally distributed. Since ANOVA is considered robust to violations of normality (Underwood 1997), data analysis was only concerned with meeting the more sensitive assumption of homogeneity of variances. Levene's test for equal variance was used since it is not affected by non-normal distributions in data. Square root transformations of the data sets were used when needed to meet the assumption of equal variances.

RESULTS

Abundances

Ibis abundances fluctuated daily and seasonally with lowest numbers during late mornings in March (lowest record: 0 birds) and highest numbers during evenings in July (highest record: 1213 birds). Ibis abundances varied significantly between sampling periods ($F_{3,59}$ = 16.08, P < 0.001) and months ($F_{4,59}$ = 26.28, P < 0.001, GLM ANOVA). In general, ibis abundances were high during the early morning and evening and low during late morning and midday (Fig. 1a). The data were homoscedastic (F = 1.63, P = 0.079, Levene's test) and no significant interaction between the factors was present ($F_{12,59}$ = 1.36, P = 0.213, GLM ANOVA). Tukey's pairwise comparisons (TPC) revealed ibis numbers were significantly higher during the early morning and evening than during the late morning (P < 0.02 for both comparisons) and midday (P < 0.01 for both comparisons). Highest abundances were in the evening and were significantly higher than during early mornings (P = 0.030, TPC), while counts during late mornings and middays were statistically similar (P = 0.971, TPC).

Ibis numbers increased consistently each month with low abundance during autumn (March and April), moderate abundance during late autumn (May) and high abundance during early to midwinter (June and July) (Fig. 1b). Ibis numbers during March, April and May were statistically similar (P > 0.40 for all comparisons, TPC), while numbers during June were significantly higher than those from March and April (P < 0.01 for both comparisons, TPC), but similar to those from May (P = 0.262, TPC). Ibis abundances reached an overall peak in July and were significantly higher than those of any previous month (P < 0.001 for each comparison, TPC). During the early morning and evening periods in July, ibis abundances were about ten times higher than those recorded in March. The data indicate that this increase was due to an influx of approximately 1000 adult birds into the park between March and July.

Movements

The number of ibis exiting and entering Centennial Park varied greatly over the months. The highest number of movements occurred during two evenings in July with 1047 and 1044 birds entering the park (Table 1). A significant interaction was found between all three factors ($F_{8,80}$ = 3.30, P = 0.003, GLM ANOVA) indicating that the number of ibis arriving and departing varied both between sampling periods and months. This interaction was due to large numbers of ibis departing the park in the morning and returning in the evening as well as a consecutive increase in the numbers of arriving and departing birds during all sampling periods from March to July (Fig. 2). Generally, during the midday sampling period between March and May no movements occurred, with only a small number of arrivals and departures during June and July.

Morning departures and evening arrivals

Ibis did not depart before first light, although they were often vocal in their roosts for up to 20 minutes before first light. Departures began during the first 10-minute interval after light, increasing substantially with each interval, reaching an overall peak between 20 and 40 minutes after first light (Fig. 3, continuous line). The amount of ibis leaving then decreased considerably, steadily reaching an overall low at the end of the sampling period (i.e. two hours after sunrise). Generally, 50 per cent of all departures took place within 40 minutes of first light. The percentage of ibis departing during each 10-minute time interval did not vary significantly among months ($F_{4,180}$ = 0.88, P = 0.477, GLM ANOVA). However, there was a significant difference among intervals ($F_{12,180}$ = 19.89, P < 0.001) indicating ibis departures from Centennial Park were not evenly distributed throughout the morning.

Evening arrivals were low during early evenings (120 to 100 minutes before darkness), and then rose consecutively with a marked increase between 40 to 30 minutes before darkness (Fig. 3, dashed line). An overall peak in arrivals occurred between 30 to 20 minutes before darkness, after which arrivals decreased rapidly. No ibis arrived after dark. Generally, over 50 per cent of all arrivals occurred between the 40 and 10 minutes before darkness sampling periods. The analysis of the data showed that the percentages of birds arriving during each 10-minute time interval during the evening varied significantly among intervals ($F_{12,167}$ = 26.03, P < 0.001) and months ($F_{4,167}$ = 3.76, P = 0.006, GLM ANOVA) with higher percentages of birds arriving during all intervals in July than compared to April (P = 0.018, TPC) and May (P = 0.022, TPC). This was due to a slightly more even distribution of ibis arrivals in July compared to April and May, resulting in statistically higher percentages of arrivals during all intervals for July. However ibis arrivals still exhibited the same temporal peaks and trends during all months.

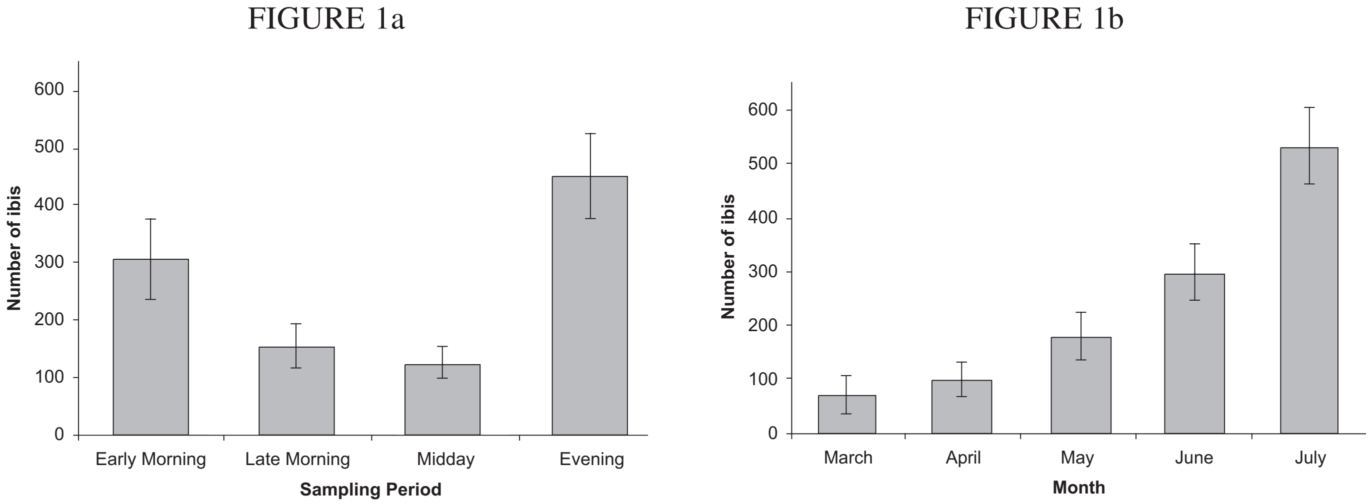

Figure 1. *Mean total abundances (±SE) of ibis in Centennial Park during each (a) sampling period (early and late morning, midday, evening), and (b) month between March and July 2003.*

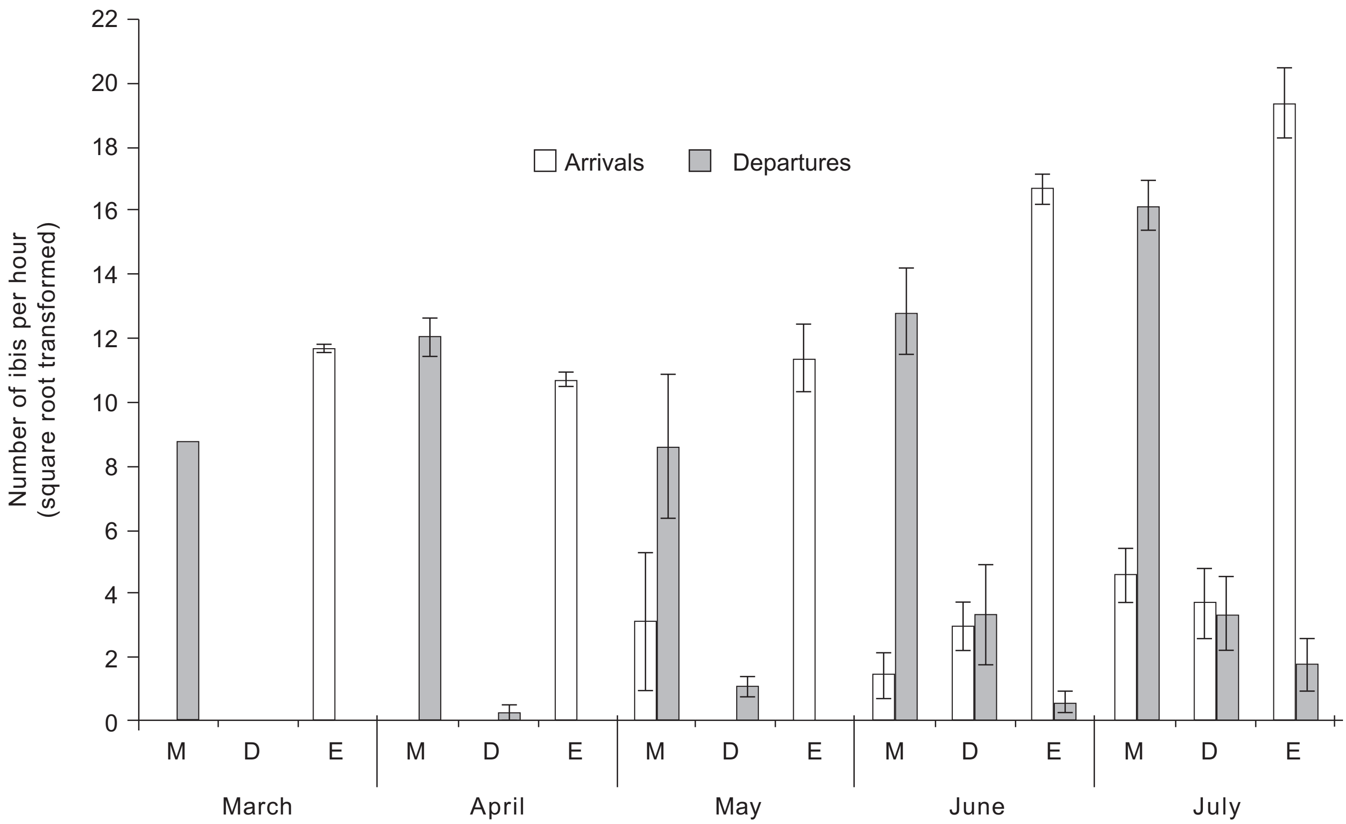

Figure 2. *Mean numbers (±SE) of ibis per hour (square root transformed) arriving and departing Centennial Park during the morning (M), midday (D) and evening (E) sampling period for each month. No standard error is shown for the morning sampling in March, since sample size equalled 1.*

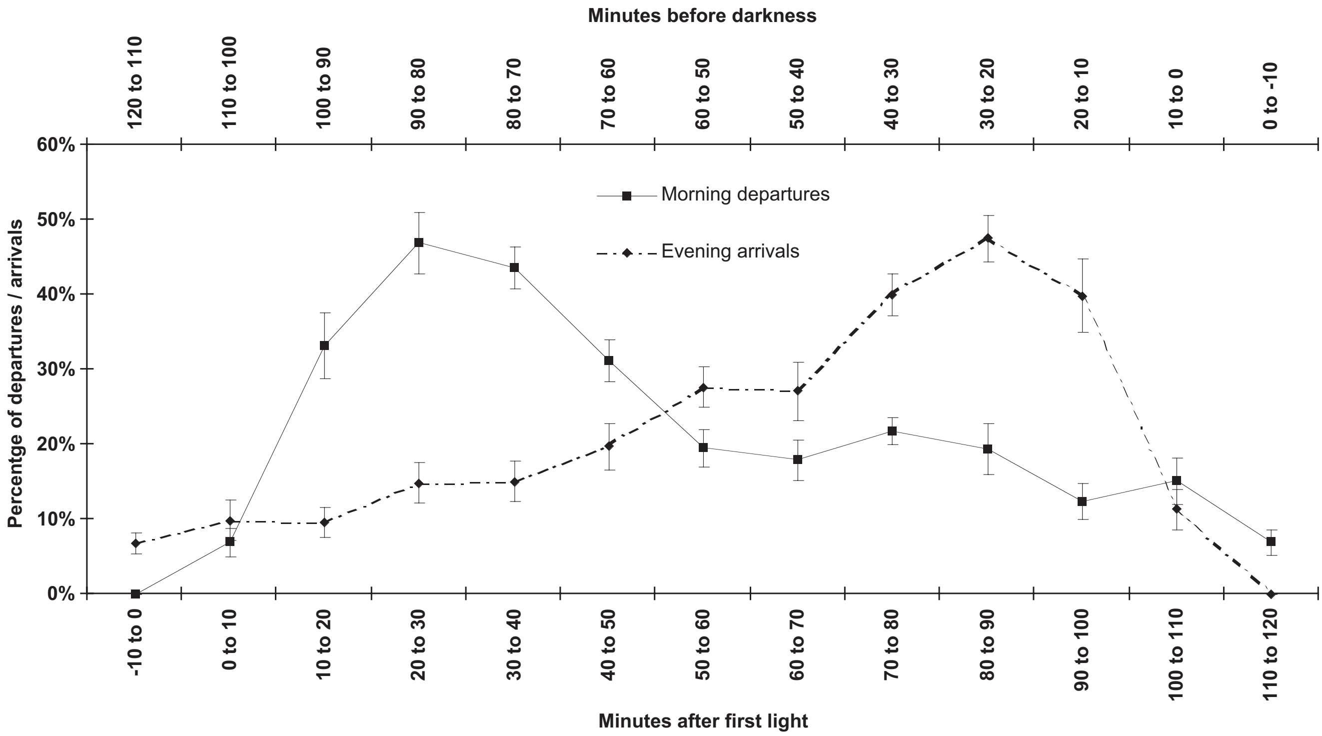

Figure 3. *Mean percentages (±SE) of ibis (data square root transformed) departing from (unbroken line) and arriving into Centennial Park (dashed line). Recording time for morning departures (bottom x-axis): 10 minutes before (= -10 min) to 120 min after first light (= 0 min). Recording time for evening arrivals (top x-axis): 120 min before to 10 min after (= -10 min) total darkness (= 0 min).*

Ibis movements were significantly oriented on all sampling days (Table 1). Ibis consistently exited and entered from the same overall direction (south-southwest to southwest) independent of month (Table 1). Over the entire study period ibis chose a highly significantly oriented mean morning departure direction of $\alpha_n = 236°$ ($r_n = 0.91$, $P < 0.001$, Rayleigh test). Similarly, in the evening the birds showed a significant return movement into the park with a mean arrival direction of $\alpha_n = 235°$ ($r_n = 0.95$, $P < 0.001$; Rayleigh test).

DISCUSSION

Abundances

Ibis abundances significantly fluctuated daily and seasonally. The majority of ibis departed Centennial Park during the early morning and did not return until the evening, with few ibis (20 to 30 birds during all months) remaining in the park to forage in open space areas. This suggests that ibis use the park primarily for overnight roosting. Although ibis are commonly associated with scavenging picnic grounds, ibis were departing Centennial Park to forage elsewhere. This coincides with other studies, where it has been reported that ibis usually depart roosts at dawn and return to them at dusk (Davis and Reid 1974; Lowe 1981; Bekle 1982) and conduct daily movements of up to 15 kilometres (Lowe 1981) and 25 kilometres (Shaw *et al.* 2002) between their communal roosts and feeding sites.

The seasonal increase in ibis abundance correlated with the transition from the non-breeding to breeding season. Abundances increased quickly from May onward, when all birds in the park had completed their pre-breeding moult (early April to late May) and were in full breeding plumage (early June) with first breeding activities recorded in late May (Corben and Munro 2006). From then on numbers of nests, eggs and hatchlings increased rapidly with nearly 250 nests at the end of July (Corben and Munro 2006). The seasonal increase was due to an increase in adult ibis only. This suggests that ibis that normally do not roost in the park were immigrating into Centennial Park to reproduce. This indicates that the ibis population of Centennial Park is comprised of a relatively small permanent sedentary subpopulation and a large mobile subpopulation that is only present during the breeding season. This hypothesis is also supported by observations from Munro (unpubl. data) and Legoe and Ross (records of DEC, Hurstville, NSW), who describe dramatic declines in ibis abundances in Centennial Park and other breeding colonies due to the departure of large numbers of mature and immature birds after the breeding period.

The results were consistent with other colonies throughout the Sydney region. Populations in the Royal Botanic Gardens, Darling Harbour, Cabramatta Flying Fox Reserve (U. Munro unpubl. data) and Lake Gillawarna, Bankstown (G. Ross, pers. comm.) grew dramatically as ibis formed large breeding colonies in these areas. The Cabramatta colony grew from no ibis to over 200 birds between April and July 2003 (U. Munro unpubl. data). At Lake Gillawarna equivalent increases occurred with estimates of 1000 birds using this site during the 2003 breeding period (G. Ross, pers. comm.). This suggests that all ibis colonies within the Sydney region may be comprised of small permanent sedentary subpopulations and large mobile subpopulations that move into Sydney for the breeding season.

TABLE 1

Morning departures and evening arrivals of ibis between March and July 2003. *m* = number of ibis arriving or departing on each sampling day; α_m and r_m = mean departure and arrival angles and vectors for each sampling day; n = number of sampling days; α_n and r_n = second order (calculated using α_m and r_m from all sampling days) mean departure and arrival angles and vectors for the whole sampling period (refer to total). All first and second order mean directions were significantly oriented towards the SSW and SW ($P < 0.001$; Rayleigh test).

Sampling Date (month, day)		Morning Departures			Evening Arrivals		
		m	α_m	r_m	m	α_m	r_m
March	21		No sampling		304	213°	0.65
	28	168	201°	0.71	289	204°	0.84
April	4	395	202°	0.88	268	210°	0.76
	10	325	204°	0.85		No sampling	
	17	306	205°	0.79	241	219°	0.76
	25	243	206°	0.84	236	233°	0.87
May	2	290	249°	0.72	226	234°	0.77
	9	212	240°	0.72	176	234°	0.84
	14	155	237°	0.64		No sampling	
	23	350	223°	0.79	345	249°	0.81
	30	312	221°	0.58	406	226°	0.72
June	6	503	285°	0.64	677	245°	0.82
	13	388	249°	0.59	545	240°	0.71
	20	408	271°	0.63	652	271°	0.75
	27	178	257°	0.80	551	262°	0.67
July	4	469	259°	0.64	702	262°	0.76
	11	451	245°	0.42	583	252°	0.70
	18	639	258°	0.48	747	236°	0.61
	25	761	226°	0.69	1047	214°	0.68
	31	542	244°	0.62	1044	223°	0.80
Total		n = 19	α_n= 236°	r_n = 0.91	n = 18	α_n = 235°	r_n = 0.95

It has been speculated that the recent drought in inland New South Wales between the end of 2002 and beginning of 2003 has dried inland wetlands, and may have forced ibis to move to the coast (G. Ross, pers. comm.). Censuses of inland wetlands during our study period found few ibis and far less than expected based on previous surveys (Porter *et al.* 2006; G. Ross, pers. comm.). Ibis can move long distances and movements over 2000 and 3000 km have been reported (Carrick, 1962; Purchase 1976; Lowe 1984). There is also evidence for long distance movements of adult ibis during dry conditions which would support the notion that ibis from the dry inland are moving into wetter coastal areas (Carrick 1962; Marchant and Higgins 1990).

Similar seasonal fluctuations in ibis abundances have been observed in Centennial Park during non-drought years (J. Cartmill, unpubl. data), which implies that ibis do not simply move coastwards during dry conditions but might do so on a regular annual basis. This would imply that partial migration exists in the Sydney ibis population. Lowe (1984) provides evidence that partial migration between breeding and non-breeding areas may exist in ibis. Partial migration and seasonal long distance movements across Australia have also been recorded for the closely related Straw-necked Ibis *T. spinicollis* (McKilligan 1975; Lowe, 1984; Marchant and Higgins 1990; Griffioen and Clarke 2002). Currently, too little is known about the movements and reproductive biology of ibis to conclude with certainty from where the ibis in Australia's coastal urbanised areas originate, and whether movements are initiated purely by environmental conditions or based on regular migrations of parts of the populations.

The movements of ibis into urban areas have implications for ibis management. Management of Sydney's and other urban ibis populations regularly involves egg and nest destruction and culling (Ross 2004; Shaw and Murray 2004). If long distance movements of ibis commonly occur, then these management practices may actually reduce regional populations rather than the local urban populations they are aimed at. Therefore, urban ibis management needs to be cautious and aware of its potential impacts on the wider ibis population until regional as well as long distance movement patterns are clarified.

Movements

This study identified key temporal and spatial patterns in the movements of ibis to and from a roost, with trends consistent between seasons. Although other studies show that ibis usually depart roosts at dawn and return to them at dusk (Davis and Reid 1974; Lowe 1981; Bekle 1982), our study reports peak times of ibis movements. Specifically, we showed that the ibis of Centennial Park departed rapidly in the morning with approximately 50 per cent of all birds departing between 20 and 40 minutes after first light. During evenings the ibis returned to the park with approximately 50 per cent of the total arrivals occurring between 40 and 10 minutes before total darkness. In contrast to the closely related Sacred Ibis (Kopij 1999), the Australian White Ibis conducted no movements before first light or after darkness. Also, very few movements occurred in the middle of the day.

Departing and arriving ibis consistently oriented their movements towards a mean south-westerly (SW) direction (236° for departures, 235° for arrivals) throughout the whole study period. Although ibis abundance increased seasonally, ibis maintained fidelity to the general SW direction. Ibis probably visit the same sites feeding daily and follow the same flight paths (see also Perry 2001). Observations of ibis movements at Sydney's International Airport (seven kilometres SW) are consistent with our results (Corben 2003). Ibis roosting at Centennial Park fly over the airport on their way to their feeding sites at a landfill (Lukas Heights) approximately 22 kilometres southwest of Centennial Park (Corben 2003; Corben and Munro 2006; D. Mulquin, pers. comm.). Similarly in the Gold Coast region, Queensland, landfills provide up to 78 per cent of the birds' primary food supply (Shaw 2001). Reducing food supply through improved landfill management appears to be essential for managing ibis effectively.

Identifying patterns and peak periods of movements of ibis are important for two reasons. Firstly, they provide a framework for conducting surveys on ibis population sizes. Population and movement data are best collected at the same time during early mornings or late evenings, otherwise a large proportion of the roosting population will not be present and counts will be low. In the past, most park managers estimated total population sizes of ibis by counting their numbers at different times during the day, usually during working hours. These methods would provide inaccurate data and underestimate total population sizes. Secondly, movement patterns of urban ibis are important for urban management and planning. In particular, knowledge of ibis movements, such as times of peak movements, can be incorporated into air traffic operations and risk management strategies to prevent bird-strike and ensure passenger and aircraft safety. A collision between a Qantas Airbus and a single ibis resulted in several million dollars worth of damage, including replacing an engine (Shaw and Murray 2004).

This study indicates that ibis abundances and movements fluctuate both daily and seasonally. In addition, the results suggest that the ibis population of Centennial Park, and possibly entire Sydney, consists of a permanently present, sedentary subpopulation as well as a mobile subpopulation that spends the non-breeding period outside Sydney and only visits Sydney for the breeding period. These findings are of major significance to urban ibis management programs. Since these programs generally aim to decrease population sizes, they may impact on the species at regional scales. However, in order to conclude on this, further research is urgently required. In particular, studies on ibis abundances, movements and population dynamics over extended temporal and spatial scales are needed.

ACKNOWLEDGEMENTS

We thank Jonathan Cartmill (Centennial and Moore Park Trust, Sydney), Geoff Ross and Cici Legoe from the Department of Environment and Climate Change, Hurstville, NSW, and David Mulquin (University of Technology, Sydney (UTS)) for their support and providing access to their unpublished data collections on ibis. Elizabeth Favaloro assisted with fieldwork. Fraser Torpy (UTS) gave statistical advice and Rod Buckney (UTS) commented on earlier drafts of the manuscript. We also thank the support staff from UTS for their technical assistance. Phil Shaw and Nick Murray (Ecosure, Queensland) provided access to information and reports on ibis management programs.

REFERENCES

Australian Transport Safety Bureau (2002). 'The Hazard posed to Aircraft by Birds'. (Australian Transport Safety Bureau, Civic Square: Canberra.)

Batschelet, E. (1981). 'Circular Statistics in Biology'. (Academic Press: London.)

Bekle, H. (1982). Sacred Ibis in south-western Australia. *W. Austral. Naturalist* **15:** 13-19.

Blakers, M., Davies, S. J. and Reily, R. N. (1984). 'Atlas of Australian Birds'. (Melbourne University Press: Melbourne, Australia.)

Briggs, S. V. and Thornton, S. A. (1999). Management of water regimes in River Red Gum *Eucalyptus camaldulensis* wetlands for waterbird breeding. *Austral. Zool.* **31:** 187-197.

Carrick, R. (1962). Breeding, movements and conservation of ibises (Threskiornithidae) in Australia. *CSIRO Wildl. Res.* **7:** 71-88.

Clergeau, P. and Yésou, P. (2006). Behavioural flexibility and numerous potential sources of introduction for the Sacred Ibis: causes of concern in western Europe. *Biol. Invas.* **8:** 1381-1388.

Corben, D. T. (2003). Population composition, abundances, and movements of the Australian White Ibis, *Threskiornis molucca* (Threskiornithidae), in an urban environment. Honours Thesis, University of Technology, Sydney.

Corben, D. T. and Munro, U. (2006). Clutch size and fledgling success of the Australian White Ibis *Threskiornis molucca* in an urban environment. *Corella* **30:** 55-58.

Cowling, S. J. and Lowe, K. W. (1981). Studies of ibises in Victoria, I: records of breeding since 1955. *Emu* **81:** 33-39.

Davis, W. A. and Reid, A. J. (1974). Victorian ornithological research group Westernport report no. 1 part 2: The birds of the Somers, Sandy Point, Hastings districts, Westernport Bay, Victoria. Vic. *Naturalist* **91:** 264-269.

Epstein, J., McKee, J., Shaw, P., Hicks, V., Micalizzi, G., Daszak, P., Kilpatrick, A. and Kaufman, G. (2007). The Australian White Ibis (*Threskiornis molucca*) as a reservoir of zoonotic and livestock pathogens. *EcoHealth* **3:** 290-298.

Griffioen, P. A. and Clarke, M. F. (2002). Large-scale bird movement patterns evident in eastern Australian atlas data. *Emu* **102:** 99-125.

Gosper, D. G. (1981). Survey of birds on floodplain – estuarine wetlands on the Hunter and Richmond Rivers in northern NSW. *Corella* **5:** 1-18.

Hancock, J. A., Kushlan, J. A. and Kahl, M. P. (1992). 'Storks, Ibises and Spoonbills of the World'. (Academic Press: London.)

Kentish, B. (1994). The effect of revegetation on Silver Gull and Sacred Ibis populations at Winter Swamp, Ballarat. *Corella* **18:** 71-76.

Kentish, B. (1999). Breeding of Australian White Ibis, Straw-necked Ibis and Silver Gull on Winter Swamp, Ballarat from 1990-1997. *Corella* **23:** 37-42.

Kingsford, R. T. and Johnson, W. (1998). Impact of water diversions on colonially-nesting waterbirds in the Macquarie Marshes of arid Australia. *Col. Waterbirds* **21:** 159-170.

Kopij, G. (1999). Breeding ecology of the Sacred Ibis *Threskiornis aethiopicus* in the Free State, South Africa. *S. Afr. J. Wildl. Res.* **29:** 25-30.

Lowe, K. W. (1981). The habitat requirements of herons, egrets, ibises and spoonbills of the Westernport region. (Environmental Studies Program, Ministry for Conservation, Victoria: Melbourne.)

Lowe, K. W. (1984). The feeding and breeding biology of the Sacred Ibis *Threskiornis aethiopicus* in southern Victoria. PhD Thesis, University of Melbourne.

Lowe, K. W. (1999). The dirt on ibis. *Nature Australia,* **Autumn:** 26-33.

Marchant, S. and Higgins, P. J. (1990). 'Handbook of Australian, New Zealand and Antarctic Birds. Vol. 1, Part B: Ratites to Ducks'. (Oxford University Press: Melbourne.)

Meyer-Gleaves, S. (2003). Synanthropy of the Australian White Ibis, *Threskiornis molucca*, in the greater Brisbane region. Honours Thesis, Griffith University, Brisbane.

McKilligan, N. G. (1975). Breeding and movements of the Straw-necked Ibis in Australia. *Emu* **75:** 199-212.

Morris, A. K. (1983). First breeding of the Sacred Ibis in the county of Cumberland. *Australian Birds* **17:** 43-44.

Morton, S. R., Brennan, K. G. and Armstrong, M. D. (1993). Distribution and abundance of herons, egrets, ibises and spoonbills in the Alligator River region, Northern Territory. *Wildl. Res.* **20:** 23-43.

Perry, J. (2001). Factors influencing the distribution of Australian White Ibis *Threskiornis molucca* in urban Sydney. Honours Thesis, University of Sydney.

Porter, J. L., Kingsford, R. T. and Hunter, S. J. (2006). 'Aerial Surveys of Wetland Birds in Eastern Australia – October 2003-2005, Occasional Paper No. 37'. (Department of Environment & Conservation, NSW: Hurstville.)

Purchase, D. (1976). The occurrence of *Threskiornis molucca strictipennis* in New Guinea. *Emu* **76:** 89.

Roberts, P. (1993). 'Birdwatcher's Guide to the Sydney Region'. (Kangaroo Press: Kenthurst.)

Ross, G. A. (2004). Ibis in urban Sydney: a gift from Ra or a Pharaoh's curse? In 'Urban Wildlife: more than meets the Eye'. (Eds D. Lunney and S. Burgin). Pp.148-152. (Royal Zoological Society of New South Wales: Mosman.)

Shaw, P. (2001). 'Australian White Ibis Management Program: Annual Report 2001'. (Ecosure Australia: Tugun.)

Shaw, P. and Murray, N. (2004). 'Australian White Ibis Management Program: Annual Report 2003/2004. (Ecosure Australia: Tugun.)

Shaw, P., Murray, N. and Periott, G. (2002). 'Australian White Ibis Management Program: Annual Report 2002'. (Ecosure Australia: Tugun.)

Underwood, A. J. (1997). 'Experiments in Ecology: their Logical Design and Interpretation using Analysis of Variance.' (Cambridge University Press: Cambridge.)

Zar, J. H. (1996). 'Biostatistical Analysis 3rd Ed.'. (Prentice-Hall: Englewood Cliffs.)