From: Pages 303-317
Conservation Biology in Asia (2006) McNeely, J.A., T. M. McCarthy, A. Smith, L. Olsvig-Whittaker, and E.D. Wikramanayake (editors). Published by the Society for Conservation Biology Asia Section and Resources Himalaya, Kathmandu, Nepal, 455 pp. ISBN 99946-996-9-5

CHAPTER 22

BIODIVERSITY CONSERVATION IN AN URBAN LANDSCAPE: A CASE STUDY OF SOME IMPORTANT BIRD AREAS ON THE RIVER YAMUNA IN DELHI (INDIA)

By

A. JAMIL URFI

Department of Environmental Biology, University of Delhi, Delhi 110007, India.
E-mail: ajurfi@rediffmail.com

ABSTRACT

Although the growing trend of urbanization is a cause for concern, few studies have explored its impacts on wildlife populations in India. This study examines changes in wintering waterfowl communities at Okhla Barrage Bird Sanctuary, in India's capital city Delhi, based on field studies conducted during 1989-95 and 2005-06. During the study period total abundance of waterfowl declined by 36%. Rarefaction plots reveal a decline in the number of species expected. Simpson's Index and Shannon Diversity for 2005 is significantly lower than in the 1990s. One of the most remarkable disappearances from Okhla has been that of the Sarus Crane (*Grus antigone*). The increase in the sightings of flamingo and a decline in the abundance of pochards is suggestive of decreasing water depths, possibly due to siltation. The wild Painted Stork population nesting in the premises of the Delhi Zoo since 1960 also offers a unique opportunity to study the effects of water pollution and urbanization on bird populations. Although the population of storks in the zoo have not declined since 1960, when this colony was established, some preliminary studies indicate that their clutch size and hatching success are being affected, which merits further investigations. Although there have been numerous public interest litigations for stopping illegal construction activity at Okhla, much remains to be achieved. Regular conservation monitoring programmes should be undertaken both at Okhla barrage and Delhi Zoo and sustained over long time periods.

Key Words: Birds, Delhi, Painted Stork, River Yamuna, Urban

INTRODUCTION

Urbanization is a frequently cited cause of species endangerment in various parts of the world (Czech & Krausman 1997), but our understanding of the ecology of urban systems and how best to manage them for the needs of both humans and wildlife is limited (McDonnell & Pickett 1990). Birds are useful biological indicators (Bibby *et al.* 1992) because they are ecologically versatile and can be monitored with ease, often with the involvement of volunteers across large spatial and temporal scales (Urfi 2004). Because of their high mobility, birds react rapidly to changes in their habitat (Morrison 1986), so their presence or absence for a particular site is consequential.

Numerous studies have been carried out on the avifauna in urban landscapes (Marzluff *et al.* 2001). This includes studies addressing species richness–area relationships (island biogeographic questions) about birds in urban reserves or parks (Park & Lee 2000), changes in bird communities across gradients of urbanization (Blair 1996; Clergeau *et al*. 1998), and studies on birds in riparian systems of urban areas, and ponds and lakes in cities (Lindsay *et al.* 2002; Rottenborn 1999; Trauti & Hostetler 2003).

In India, several studies have focused on changes in bird populations and distribution in natural habitats (Urfi *et al*. 2005), but very few have attempted to investigate the impacts of urbanization on birds. However, many Indian cities offer foraging and nesting habitats for birds, especially colonial waterbirds such as egrets, herons, cormorants, storks, ibis, spoonbills and pelicans. More than 45% of all heronries in India are located in parks and gardens in urban areas (Subramanya 1996). Additionally, Important Bird Area's (IBAs) affording sizeable populations of resident and wintering waterfowl exist on rivers within several cities. Whether protected or otherwise, such patches of wilderness are usually the first victims of urban expansion and may end up as habitat islands in a sea of concrete. Urban areas also have unique advantages when it comes to monitoring bird populations, partly because of the presence of a large number of volunteers who have easy accessibility to IBAs and the means to participate in bird census programmes and other conservation-related activities (Urfi 2004).

IBA's along the river Yamuna, Delhi

India's capital city, Delhi, is ornithologically very rich (Ganguli 1975; Zoological Survey of India 1997) and many IBAs exist along the 22 km stretch of the river Yamuna which passes through it (Islam & Rahmani 2004). Okhla Barrage, located at the point where the river Yamuna leaves the territory of Delhi and enters the neighboring state of Uttar Pradesh, is one of the most important IBA sites on the Yamuna (Urfi 2003). Historically, the south portion of Delhi's Yamuna did not have any large impoundment of water (Figure 1A) until the construction of the barrage in ca 1911 (Figure 1B). The sheet of water at Okhla grew larger in size after the creation of the new Okhla barrage in 1989 (Figure 1C), which started attracting large numbers of wintering waterfowl. In 1990, an area of 3.5 km^2, sandwiched between Okhla village and Gautambudh Nagar and including the large lake created by damming the river (Figure 2) was notified as a bird sanctuary by the Uttar Pradesh government under the Wildlife Protection Act of India. Reed beds (*Typha angustata* and *Phragmites maxima*) are abundant in the marshy areas of the sanctuary, while patches of Water Hyacinth (*Eichhornia crassipes*) form dense mats across the barrage (Urfi 2003).

The main bird habitats identified at the site are: *Shallow vegetated areas* (areas 1–5 in Figure 2); *Deep areas* (areas 7, 10 and 12); *Ponds* (areas 9 and 14; the second pond was largely destroyed by road building activity in 2001); *Reed beds* (areas 6 and 13); and *Sand flats and grassy areas* (area 8). A total of 302 species have confirmed records from Okhla bird sanctuary and the areas in its immediate vicinity, and an additional 27 species have been listed as probable, but unconfirmed (Urfi 2003). Some birds of conservation importance recorded at Okhla are ***Critically Endangered:*** White-rumped Vulture (*Gyps bengalensis*), Indian Vulture (*Gyps indicus*), (***Vulnerable***) Baikal Teal (*Anas formosa),* Baer's Pochard (*Aythya baeri),* Sarus Crane (*Grus antigone*), Sociable Lapwing (*Vanellus gregarious*), Indian Skimmer (*Rynchops albicollis*), Pallas's Fish Eagle (*Haliaeetus leucoryphus*), Lesser Adjutant (*Leptoptilos javanicus*), Bristled Grassbird (*Chaetornis striatus*), Finn's Weaver (*Ploceus megarhynchus*); ***Near Threatened***: Ferruginous Pochard (*Aythya nyroca*), Black-bellied Tern (*Sterna acuticauda*), Grey-headed Fish Eagle (*Ichthyophaga ichthyaetus*), Darter (*Anhinga melanogaster*), Black-headed Ibis (*Threskiornis melanocephalus*), Painted Stork (*Mycteria leucocephala*), Blacknecked Stork (*Ephippiorhynchus asiaticus*); and, ***Conservation Dependent***: Dalmatian Pelican (*Pelecanus*

crispus). During the 1990s, the waterfowl population recorded at Okhla in winter was in excess of 25,000 (Urfi 2003). This figure excludes several species of small and large waders (members of families Scolopacidae, Charadriidae, Ardeidae, Phoenicopteridae, Threskiornithidae and Ciconiidae) which occur at Okhla barrage. If their numbers are also taken into account then the population of wintering waterfowl would be much larger, and on the basis of criteria for waterfowl numbers, Okhla barrage could qualify for inclusion in the list of Ramsar sites.

Another IBA associated with the river Yamuna is the National Zoological Park (also known as the Delhi Zoo) which is located about 9 km upstream from Okhla barrage, on the western bank of the river, and provides a nesting habitat for several species of free-ranging heronry birds (families *Phalacrocoracidae, Ardeidae, Threskionithidae and Ciconiidae*). Besides Painted Stork which has been regularly visiting the zoo since 1960 (Desai 1971; Desai *et al*. 1974, 1977; Urfi 1997), the list includes Blackheaded Ibis (*Threskiornis melanocephalus*), Indian Cormorant (*Phalacrocorax fuscicollis*), Little Cormorant (*Phalacrocorax niger*), Indian Pond-Heron (*Ardeola grayii*), Cattle Egret (*Bubulcus ibis*), Little Egret (*Egretta garzetta*), Intermediate Egret (*Mesophoyx intermedia*) and Black-crowned Night-Heron (*Nycticorax nycticorax*). The zoo's extensive network of ponds and canals, where the nesting sites of Painted Stork and other species are located, is fed by the river Yamuna about 1 km away and by bore wells sunk in the park. Three ponds of the zoo, which are a part of the interconnected canals, have islands (approximately 0.8 ha each) planted with mesquite trees (*Prosopis juliflora*) whose canopies merge and appear to be continuous (Figure 3). The zoo authorities dump about 60-70 kg of dead fish per day into the three ponds combined. While this fish is meant primarily for the pinioned exhibits, some of it is also consumed by the wild heronry birds, especially Painted Stork. It has been established by direct observation that during the period August to March, when Painted Stork are nesting in the zoo premises, they undertake foraging flights in and out of the zoo, several times during the course of the day (Desai 1971), as they go to feed on the marshes associated with the river Yamuna, particularly in the direction of Okhla barrage.

This review is based on field studies of waterbirds conducted at Okhla barrage across two distinct time periods: 1989-95 and 2005-06. I document the changes that have taken place in the abundance and community structure of waterfowl at Okhla. Wherever possible I have attempted to take stock of changes in bird diversity in a larger, historical context, by examining published as well as unpublished information. I discuss the conservation implications of this work, particularly the need to integrate Okhla with other IBA's (such as Delhi Zoo) so as to make conservation of wetland birds in an urban setting more meaningful. I also take stock of some recent conservation activities at Okhla and discuss their significance.

Changes in bird habitats

Major changes have taken place in the immediate environment of Okhla barrage and Delhi zoo over the past few decades. As is evident from Fig 1(C & D), the 1980s and 1990s witnessed an unprecedented increase in the amount of built up areas along the banks of the river Yamuna (Pucher *et al*. 2005). During the corresponding period, the levels of pollution of the river increased exponentially (Central Pollution Control Board 2000). Although the stretch of the Yamuna passing through Delhi constitutes only 2% of its catchment area, it contributes about 80% of the river's total pollution load because 16 major drains dispose untreated municipal wastewater. Approximately 2270 million liters of waste water per day pours into the river, in which approximately 300 million liters per day are from the industrial sector, mostly small-scale industrial units. Recent studies have reported high concentrations of heavy metals in this stretch of the river (Rawat *et al*. 2003), as well as residues of pesticides (Aleem & Malik 2005). Casualties of fishes and birds have been reported from this river (Rawat *et al*. 2003). Fishing is commonly practiced at Okhla, and recently some instances of bird deaths, suspected to be due to poisoning, have come to light (Sundar 2006).

METHODS

Okhla Barrage

During 1989-90, bird count exercises were undertaken about 10 times (generally in the forenoon between 8-11 AM) on clear days, in the months November – February. Waterbirds were counted from the Right Marginal Bund (Fig 2, areas 1-5), main barrage (Figure 2, areas 7 & 10) and the Left Afflux Bund (Figure 2, areas 11- 14). On any given day a complete coverage of the barrage was not possible and therefore the count figures are underestimates, representing about 2/3 of the entire population of waterfowl at Okhla. Data for the year 1995 was taken from Madge (Steve Madge, Personal communication) as reported in Urfi (2003). Although all species of waterbirds in view were counted, for the purpose of analysis, only waterfowl belonging to families Anatidae, Dendrocygnidae, Anhingidae, Phalacrocoracidae and Podicipedidae were taken into consideration (Appendix 1). While Rails (Rallidae) were included, large and small waders, as well as some other categories of aquatic birds such as kingfishers, jacanas etc. (families Alcedinidae, Cerylidae, Jacanidae) were excluded from the analysis. The justifications for this are: a) due to the distances involved, particularly while counting birds from the Left Afflux Bund, a haze above the water hindered the proper identification of birds, particularly the small waders. Since their count figures were not reliable, it was decided to exclude these data from the analysis; b) birds, such as kingfishers and jacanas were excluded because their existence was most probably under-recorded on most visits, because they were generally overlooked. It was felt that their inclusion could introduce errors in the data.

The data for the period 1989-95 were pooled, and the maximum abundances for each species were taken. Field studies were repeated during 2005-06, in the months November, December and March, following the protocol described above. The data were keyed into a Minitab Worksheet (version 13.32) and analysis of the data, pertaining to the two different time periods, was done as follows. Waterfowl Abundnace (N) - total number of birds in each sample, and Species richness (S) - Number of species in the sample, were estimated for each sample. In addition, Simpson's Diversity (1/D) and Shanon Diversity (Shannon H' Log e) were calculated. Formulas for calculating these statistics and discussions of their strengths and weaknesses are discussed in greater detail elsewhere (Magurran 2004). It may be added here that if there were violations of the basic assumptions underlying the above indices, then the errors would be uniform for both sets of data, since the same data recording protocol was used in both the periods of study. Comparisons between the two data sets used a t test; t and variance of the two samples were estimated following Magurran (2004). Rank-abundance plots and rarefaction plots were made using the program Biodiversity Professional.

Delhi Zoo

Field studies on the Painted Stork population of the Delhi Zoo were conducted during August – June during 1989-92 and 2004-05. In each of the three ponds of the zoo (Figure 3) the number of adult Painted Stork were counted on a fortnightly basis from a distance of approximately 30 meters with the aid of a hand digital counter and binoculars. Since the number of birds counted at roost was maximum in late evenings, the monthly data on Painted Stork populations presented here pertains to evening roost counts. All active nests in the zoo were counted on a fortnightly basis. To compare present day observations with earlier periods, published data sets (Desai 1971; Desai *et al*. 1977) were examined. Data on population size and nests for the periods 1988-1991 and 2002-2003 were taken from Urfi (1997) and Urfi (unpublished observations), respectively.

RESULTS

Okhla

Ornithological records dating to 1943 testify to Okhla barrage having been an IBA (Hutson 1954). A number of large roosts of egrets and herons have been recorded from Okhla (Ganguli 1975), but during our surveys in 2004-05 we found that these are now restricted to only a few large trees, located between the wier and left afflux bund on the eastern side of the barrage (Figure 2). Two species of vultures - White-rumped Vulture and Indian Vulture - were numerous at Okhla prior to 1992. A roost existed on a large *Ficus* tree near the wier and the road leading to the Right marginal bund (Figure 2). However, their disappearance from Okhla is probably linked to factors responsible for the decline of *Gyps* vultures in other parts of the country over the past decade. At Okhla, one of the most remarkable disappearances has been that of the Sarus Crane. In the present study, pairs were sighted sporadically from the agricultural fields and marshes outlying the lake prior to 1992. One particular Sarus habitat has now been destroyed by the construction of a motorway (Figure 1D). There have not been any recent sightings of Sarus from Okhla. While during the period 1990-95, Great White Pelican (*Pelecanus onocrotalus*) and Dalmatian Pelican were observed on a number of occasions, their sightings have now become rare. The nesting habitats of Bronze-winged Jacana (*Metopidius indicus*) and Lesser Whistling Duck, both recorded from Okhla as new breeding records for the Delhi region (Urfi 1996), have disappeared due to construction of a bridge adjacent to the area where their nests/young were located (Urfi 1997). Up to 1990, Greater Flamingo (*Phoenicopterus ruber*) were sparse at Okhla but during our recent visits we found their occurrence and abundance has increased. The, populations of feral birds such as kites, crows, and mynas has also increased, especially along the right marginal bund.

Table 1. A comparison of various ecological diversity parameters during 1990-95 and 2005-06 at the Okhla Barrage Bird sanctuary. For details see text.

Parameters	**1990-95**	**2005-06**
Waterfowl abundance(N)	25112	8940
No. Species in the sample(S)	27	20
Diversity (1/D)	5.711	3.022
Shanon Diversity (Shannon H' Log e)	2.008	1.581

A marked reduction in the numbers of wintering waterfowl is to be observed at Okhla (Table 1). The rarefaction results (Figure 4) show that the asymptotic value of expected species in the 1989-95 data set is much higher than that in 2005-06 data. Species richness and diversity for the first data set are also much higher than the second (Table 1). The Shanon Diversity Index of the 2005-06 data is significantly lower than that for the 1989-90 data (t test, $p<0.001$). The rank-abundance plots for the two data sets reveal some important differences (Figure 5). During 2005-06, the abundance of the top ranked waterfowl are much less than those in the earlier data set, indicating an overall decline in waterfowl abundance. The plot of 1989-95 data has a much longer tail and a characteristic hump, which is not present in the second data set indicating a greater evenness in the sample. Infact, the curve for the 2005-06 data set is much steeper, approximating a logarithmic distribution, characteristic of altered community structure in stressed environments (Magurran 2004). Thus, in the latter period, not only are there fewer species in the sample, but also the bulk of the biomass is composed of just a few species. Five species ranked highest in terms of their abundance in the earlier data set are Pintail, Coot, Gadwall, Shoveller and Common Teal, and they account for 84% of all birds in the sample. The 2005-06 data show some marginal changes in the species composition of the five most abundant species in that Spotbill in the

2005-06 data replaces Gadwall and together these five species account for 89% of all birds present in the sample. That, the four species of pochards accounted for about 9 % of the sample in 1989-95 but only 2 % in 2005-06 suggests that the habitat is getting less hospitable for diving ducks.

Population changes in the Painted Stork population of the Delhi zoo during 1960-2005

In 1960, when the first batch of Painted Stork nested in the Delhi zoo, about 60 birds were recorded (Desai *et al*. 1977). Thereafter, except for 1966, when 438 individuals were recorded (Desai 1971), population records for the intervening period are not available in literature. However, we learn from anecdotal sources (J.H. Desai, Personal communication) that in the mid- and late-1960's the yearly numbers of Painted Stork in the zoo ranged between 300-500. Since the number of storks per year cannot be ascertained from the available data, very limited data pertaining to the 1960s period are available. However, for those years for which data on both nest numbers and adult numbers per year are available, nest number is correlated with total adults counted ($r = 0.943$, $n = 10$). Being largely piscivorous, Painted Storks are dependant upon the monsoon rain because of its influence on fish reproduction (Urfi 1998). They have been recorded to skip nesting altogether in years of scanty rainfall or drought (Ali & Ripley 1987). The yearly variability in numbers of Painted Stork congregating in the Delhi zoo can be partly explained by the variability in rainfall. We conclude that there is no significant decline in the adult populations of Painted Stork nesting in the Delhi zoo from the 1960s till now (Figure 6).

DISCUSSION

Although this study demonstrates changes in abundance and community structure of waterbirds at Okhla over the last 15 years, more studies would be required before a cause-effect relationship can be established between the two. The decline in the population of diving waterfowl is suggestive of a decrease in water depth of the Okhla barrage due to siltation, since pochards are known to prefer deeper wetlands (Ali & Ripley 1987). The increase in the populations of Greater Flamingo could also be linked to alterations in water depth, as well as changes in the chemistry of the river water. An increase in populations of feral birds such as kites, crows, and mynas is probably linked to the increase in houses and other settlements that have mushroomed on the western bank of Okhla Barrage. Interestingly, the number of sightings of rare birds at Okhla continues to remain high (Urfi 2003). This is most likely due to the high frequency of birdwatchers and nature lovers -- locals as well as visitors who frequent Okhla -- and may not necessarily reflect upon the condition of the habitat for birds.

Given that several environmental changes have taken place in the immediate vicinity of the Delhi zoo, a decline in numbers of Painted Storks nesting at the site was expected, but our results are to the contrary. In spite of availability of some information about the pollution status of the river Yamuna, there is as yet no concrete evidence that the pollution in the river is adversely affecting the abundance and distribution of fish, the principal prey of Painted Stork. However, a possible explanation for there being no observable change in the Painted Stork population of the zoo could be that many natural heronries in the countryside are disappearing and therefore the storks have no alternative but to use traditional and safe sites for nesting, such as the Delhi Zoo. Observations made during 2004-05 (A. J. Urfi & T. Meganathan, unpublished observations) indicated that the clutch size as well as hatching success was slightly lower than the value reported for the period 1966-71 by Desai *et al*. (1977). Studies are underway to confirm these trends. Interestingly, the number of species nesting in the heronries of the Delhi zoo has actually increased over the last few decades. In the late 1980s Blackheaded Ibis started nesting in the zoo due to the efforts of the zoo staff when they released some captive bred birds (Urfi 1997). These birds, probably nesting for the first time since the zoo was established, quickly established themselves and have been regularly nesting in Ponds 1 and 3. The nesting of White Pelican in the zoo constitutes a new

nesting record for the Delhi region (Urfi 1997). During 1992 some males from the wild mated with captive, pinioned female birds in pond 2 and produced young.

From the viewpoint of conservation, there have been a number of recent developments at Okhla where local environmental groups are actively campaigning to save the site from illegal constructions and encroachments. A Public Interest Litigation (PIL) against the grant of fishing licenses in the River Yamuna and against the construction of a crematorium and some other structures within the protected area was filed in 2004 (Mazumdar 2005). However, in spite of considerable public interest in the conservation of this sanctuary, much remains to be done. The sanctuary staff have an ineffective plan for policing and catching offenders, and that is why activities like illegal fishing, poaching and killing are still rampant. No effort has been made by the Forest Department officials to initiate bird census, either by their own staff or by involving volunteers. Given the large human population that lives on the western bank, no plan has been made to involve the local community and target them for environment education. As far as the zoo is concerned, although having a virtual bird sanctuary in its premises is its distinctiveness, here also the authorities have no plan, either for monitoring or conserving the heronry birds, since their entire focus is restricted, perhaps justifiably so, to taking care of their captive charges. But given the conservation importance of the heronry birds of the Delhi zoo, it is essential that the zoo develops a research wing which could continue with a wild bird population monitoring programmes on a routine basis. This programme could be developed so as to involve volunteer birdwatchers to help in counting birds.

CONCLUSIONS AND RECOMMENDATIONS

The present study demonstrates that significant changes in abundance and community structure of birds have taken place at Okhla within the last 15 years, and its biodiversity values have declined considerably. Flagship species such as the Sarus Crane have disappeared from the area. The Painted Stork population of the Delhi zoo has been studied sporadically, but there is a need to initiate a long-term conservation monitoring programme, beyond the duration of individual research projects. In the process of developing these programmes existing programmes can be fine-tuned by adding more fitness parameters as well as including more species of heronry birds, for regular and sustained conservation monitoring. However, at both sites detailed ecological and toxicological studies are also necessary in order to establish a cause-effect relationship between the increasing trend of urbanization and pollution and the decline in biodiversity values. At the level of planning and policy making, the following recommendations should be taken into account:

- Initiation of a long-term conservation monitoring programme for heronry birds nesting in the Delhi zoo. This programme should be institutionalized at the zoo and sustained by its, own staff and run with the help of volunteers. The Delhi zoo programme will go a long way in enhancing our understanding of population declines in birds, and can serve as a model for initiating similar programmes in other urban heronries.
- Develop community-level nature education programmes at Okhla, including a nature interpretation centre.
- Given that there is a strong interdependence of waterbirds (particularly heronry birds) between Okhla and the Delhi Zoo, there is a need to integrate the two sites in land use planning and in the formulation of conservation strategies.
- There is also an urgent need to control the various ecosystem stressors, especially pollution, siltation and the increasing encroachments on the banks and floodplain of the river Yamuna.

ACKNOWLEDGMENTS

During the initial phase of this work I was a recipient of a research associateship awarded by the Council for Scientific & Industrial Research, Delhi, at the School of Environmental Sciences, Jawaharlal Nehru University, Delhi. During the second phase of this study (2003 onwards) I was awarded a research grant from the Ministry of Environment & Forests, Government of India, Delhi. I wish to thank Professors L. K. Pande, T. R. Rao and C. R. Babu for encouragement. This work could not have been done without the help of several colleagues and students. I wish to particularly thank Bikram Grewal, Suresh Sharma, T. Meganathan, Abdul Kalam and M. Mahindiran for offering comments, suggestions and help in the field. A part of this work was presented at the first Asia section meeting of the Society of Conservation Biologists held in Kathmandu, Nepal in 2005. I thank Jeff McNeely for inviting me to write this review.

REFERENCES

Aleem, A., and A. Malik. 2005. Genotoxicity of the Yamuna River water at Okhla (Delhi), India. **Ecotoxicol. Environ. Saf. 61:** 404–412.

Ali, S., and S. D. Ripley. 1987. **Handbook of the birds of India and Pakistan.** Oxford University Press, Delhi.

Blair, R. B. 1996. Land use and avian species diversity along an urban gradient. **Ecological Applications 6:** 506-519.

Bibbly, C., N. D. Burgess, and D. A. Hill. 1992. **Bird Census Techniques.** Academic Press, Oxford, U.K.

Birdlife International 2001. **Threatened birds of Asia: The Birdlife International Red Data Book.** Cambridge, U.K.

Central Pollution Control Board. 2000. **Water quality status of Yamuna River**. ADSORBS/32/1999-2000, Delhi.

Czech, B., and P. R. Krausman. 1997. Distribution and causation of species endangerment in the United States. **Science 277:** 1116-1117.

Clergeau, P., J. P. Savard, G. L. Mennechez, and G. Falardeau. 1998. Bird abundance and diversity along an urban-rural gradient: a comparative study between two cities on different continents. **Condor 100:** 413-425.

Desai, J. H. 1971. Feeding ecology and nesting of Painted Storks *Ibis leucocephalus* at the Delhi Zoo. **International Zoo Yearbook 11:** 208-215.

Desai, J. H., R. V. Shah, and G. H. Menon. 1974. Diet and food requirements of Painted Storks at the breeding colony in the Delhi Zoological Park. **Pavo** 12: 13-23.

Desai, J. H., G. H. Menon, and R. W. Shah. 1977. Studies on the Reproductive pattern of the Painted Stork, *Ibis leucocephalus,* Pennant. **Pavo 15**: 1-32.

Eicher Goodearth Limited**. 2001. Delhi City map**. Eicher Goodearth Limited, New Delhi.

Ganguli, U. 1975. **A guide to the birds of the Delhi area.** Indian Council of Agricultural Research, New Delhi.

Hutson, H. P. W. 1954. **The birds about Delhi**. Delhi Birdwatching Society, Delhi.

Islam, M. Z. and A. R. Rahmani.. 2004. **Important Birds Areas in India: Priority sites for conservation**. Indian Bird Conservation Network: Bombay Natural History Society and BirdLife International, UK.

Lindsay, A. R., S. S. Gillum, and M. W. Meyer. 2002. Influence of lakeshore development on breeding bird communities in a mixed northern forest. **Biological Conservation 107:** 1–11.

Magurran, A. 2004. **Measuring Biological Diversity**. Blackwell Science.

Mazumdar, S. 2005. Illegal structures demolished in Okhla Bird Sanctuary**. Protected Areas Update** vol XI no. 4, p.15

McDonnell, M. J., and S. T. A. Pickett. 1990. Ecosystem structure and function along urban–rural gradients: an unexploited opportunity for ecology. **Ecology** 7**1**: 1232–1237.

Morrisson, M. L. 1986. Bird populations as indicators of environmental changes. **Current Ornithology 3:** 429–451.

Marzluff, J. M., R. Bowman, and R. Donnelly. 2001. (Eds). **Avian Ecology and Conservation in an Urbanizing World**. Kluwer Academic Publishers, Boston, USA.

Park, C. R., and W.S, Lee. 2000. Relationship between species composition and area in breeding birds of urban woods in Seoul, Korea. **Landscape Urban Plann**. **51:** 29–36.

Pucher. J., N. Korattyswaropam, N. Mittal, and N. Ittyerah. 2005. Urban transport crisis in India. **Transport policy 12**: 185-198.

Rawat, M., M. C. Z. Moturi, and V. Subramanian.. 2003. Inventory compilation and distribution of heavy metals in wastewater from small-scale industrial areas of Delhi, India. **J. Environ. Monit. 5**: 906-912.

Rottenborn, S. C. 1999. Predicting the impacts of urbanization on riparian bird communities. **Biological Conservation 88:** 289-299.

Subramanya, S. 1996. Distribution, status and conservation of Indian heronries. **JBNHS 93**:459-480.

Sundar, K. S. G. 2006. ICWWG Field Report 2006: 2. Bird deaths at Okhla Bird Sanctuary, Gautam Buddh Nagar, Uttar Pradesh. February 4-7, 2006. WPSI and ICF, India.

Survey of India, 1989. Antique Map. Sketch of the Environs of Delhi circa 1807.

Survey of India, 1980. Delhi, Haryana, Uttar Pradesh. Map No. 53H/6.

Survey of India, 1996. Delhi Map.

Trauti, A. H. and M. E. Hostetler. 2003. Urban Lakes and Waterbirds: Effects of development on Avian Behavior. **Waterbirds 26:** 290-302.

Urfi, A. J. 1996. On some new breeding records of waterbirds from the Delhi region. **JBNHS 93**: 94 – 95.

Urfi, A. J. 1997. The significance of Delhi Zoo for wild waterbirds, with special reference to the Painted Stork *Mycteria leucocephala.* **Forktail 12** :87 - 97.

Urfi, A. J. 1998. A monsoon delivers storks. **Natural History 107**: 32-39.

Urfi, A. J. 2003. The birds of Okhla barrage bird sanctuary, Delhi, India. ***Forktail***.19: 39-50.

Urfi, A. J. 2004. **Birds, Beyond Watching.** Universities Press, Hyderabad, India.

Urfi, A. J, M. Sen, A. Kalam, and T. Meganathan. 2005. Counting birds in India: A review of methodologies and trends. **Current Science 89:** 1997-2003.

Zoological Survey of India. 1997. Fauna of Delhi. **State Fauna Series** 6, Zoological Survey of India, Calcutta.

Fig. 1: Maps to show the changes around River Yamuna in Delhi between the region Delhi Zoo and Okhla. A) *ca.* 1807 (Source: Survey of India, 1989); B) *ca.* 1975 (Source: Survey of India, 1980); C) *ca.* 1996 (Source: Survey of India, 1996); and D) *ca.* 2001 (Source : Eicher Goodearth Limited 2001). Dark shaded areas in all maps denote built up areas and the light shaded areas denote waterbodies and sand flats. Symbols used: Z, Delhi Zoo; H, Humayun's Tom; O, Okhla village; and P, Patparganj (only in A and B).

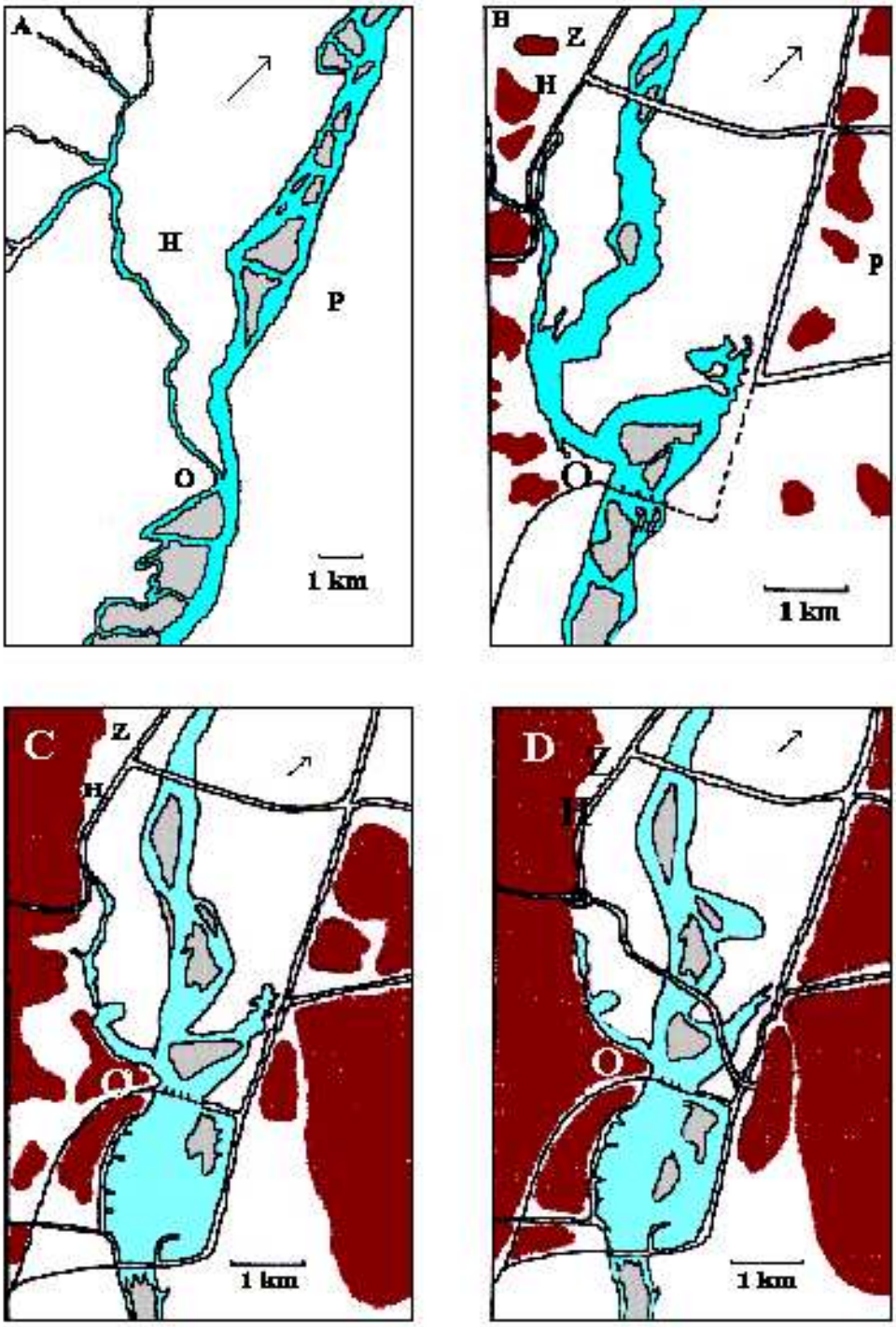


Fig 2: Map of Okhla Barrage Bird Sanctuary showing the main habitat areas (1-14) described in the text. The dashed line denotes the boundary of the bird sanctuary; the dashed and dotted line demarcates the state border between Delhi and Uttar Pradesh. Note the location of the weir, old and new Agra canal and the barrage

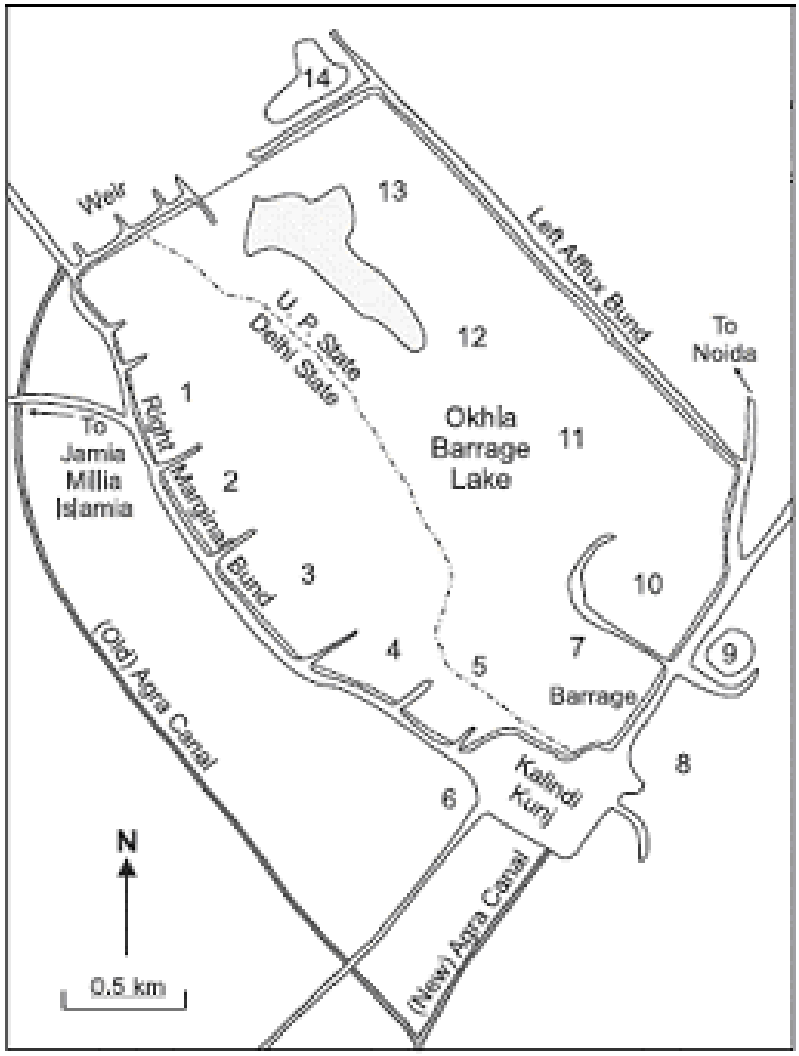


Fig. 3: Map of the Delhi Zoo showing the three principal ponds (1, 2 and 3) with heronries of Painted Stork.

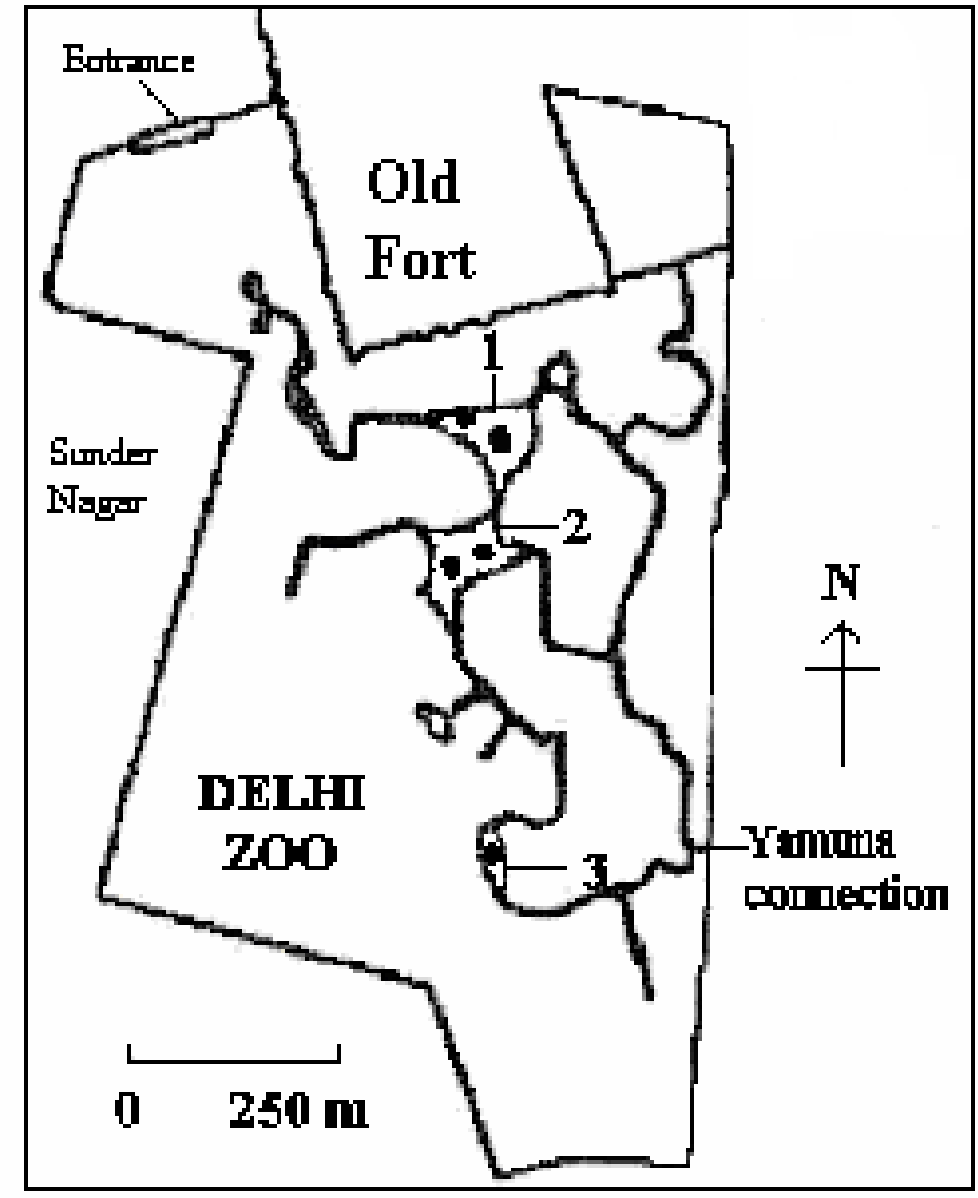


Fig. 4: Cumulative species-individual relationships for waterfowl at Okhla barrage censused during 1990-95 and 2005-06.

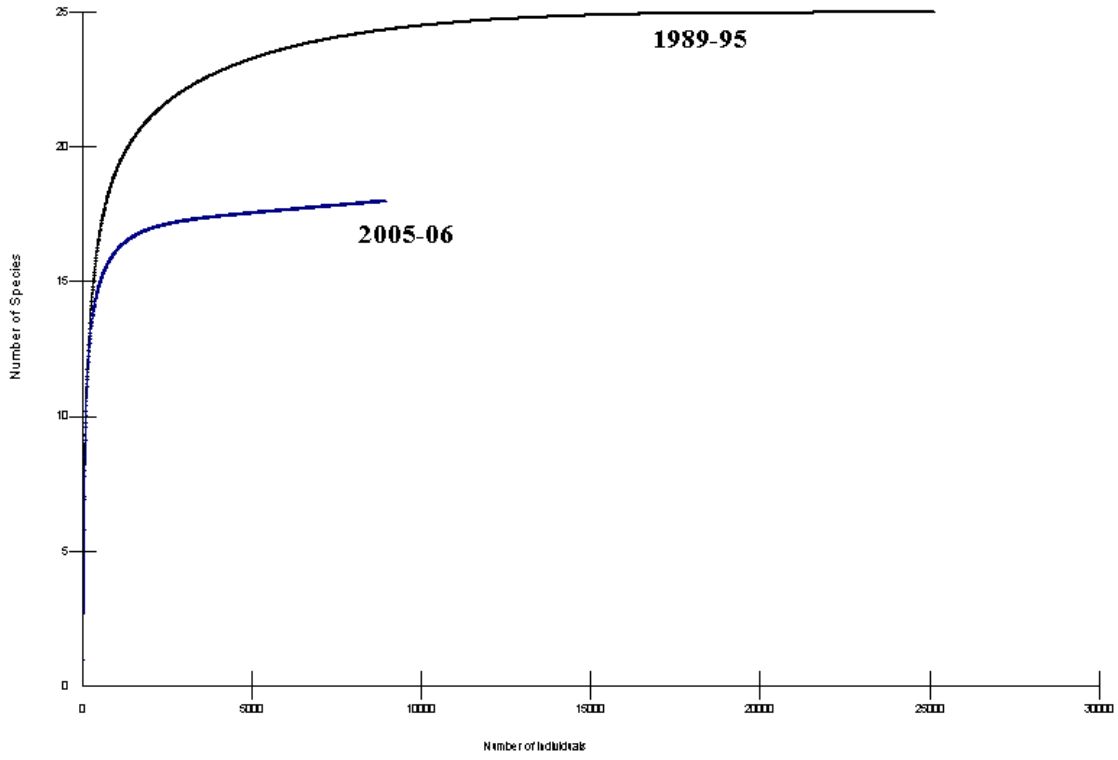


Fig. 5: Rank abundance plots for waterfowl at Okhla barrage censused during 1990-95 and 2005-06.

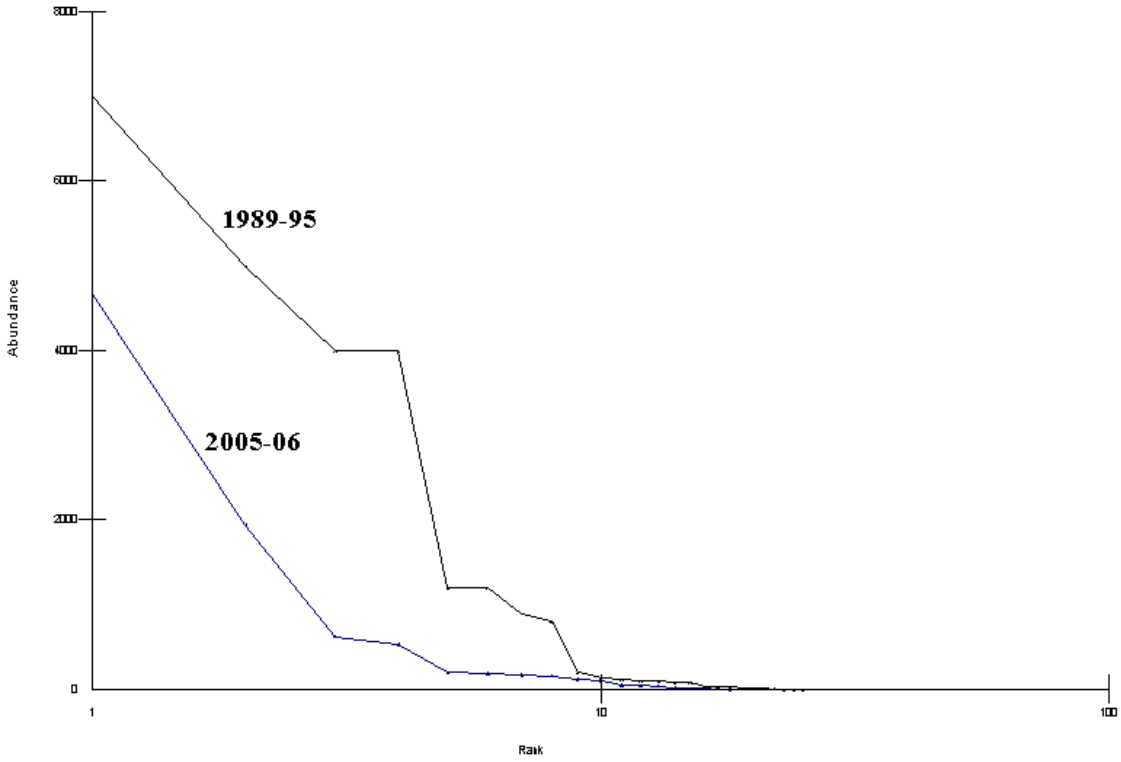
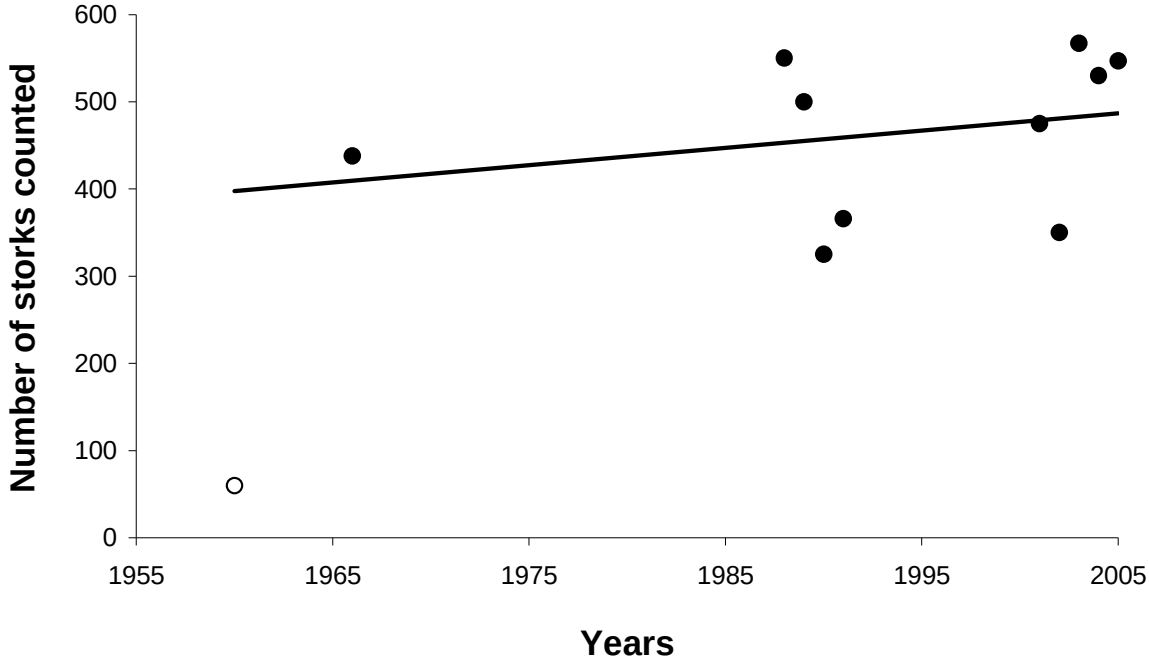


Fig. 6: Population trends of the Painted Stork nesting in the Delhi Zoo from 1966-2005. ○ denotes the data in the founding year (1960) and has been excluded from the trend line. For details see text.



Appendix 1. Species of waterfowl recorded at Okhla barrage during the study period that were used in the analysis reported in this study. Symbols used: R= resident, M= migratory

Species	**Status**
Lesser Whistling Duck *Dendrocygna javanica*	R
Greylag Goose *Anser anser*	M
Bar-headed Goose *Anser indicus*	M
Ruddy Shelduck *Tadorna ferruginea*	M
Cotton Pygmy-Goose *Nettapus coromandelianus*	R/M
Gadwall *Anas strepera*	M
Eurasian Wigeon *Anas penelope*	M
Mallard *Anas platyrhynchos*	M
Spot-billed Duck *Anas poecilorhyncha*	R
Northern Shoveller *Anas clypeata*	M
Northern Pintail *Anas acuta*	M
Garganey *Anas querquedula*	M
Common Teal *Anas crecca*	M
Red-crested Pochard *Rhodonessa rufina*	M
Common Pochard *Aythya ferina*	M
Ferruginous Pochard *Aythya nyroca*	M
Tufted Duck *Aythya fuligula*	M
White-breasted Waterhen *Amaurornis phoenicurus*	R
Common Moorhen *Gallinula chloropus*	R
Common Coot *Fulica atra*	R/M
Little Grebe *Tachybaptus ruficollis*	R
Great Crested Grebe *Podiceps cristatus*	M
Darter *Anhinga melanogaster*	R
Little Cormorant *Phalacrocorax niger*	R
Indian Cormorant *Phalacrocorax fuscicollis*	R
Great Cormorant *Phalacrocorax carbo*	R