Asian Journal of Conservation Biology, July 2023. Vol. 12 No. 1, pp. 111–120 AJCB: FP0216/78132
ISSN 2278-7666 ©TCRP Foundation 2023 https://doi.org/10.53562/ajcb.78132

Research Article

Population size and factors affecting the distribution of *Pelecanus philippensis* (Pelecaniformes: Pelicanidae) in Colombo district, the Western province of Sri Lanka

Ayoma Senanee Weerasinghe[1] & Udaya Priyantha Kankanamge Epa[2]*

[1,2]*Department of Zoology and Environmental Management, Faculty of Science, University of Kelaniya, Kelaniya 11600, Sri Lanka*

(Received: November 20, 2022 ; Revised: January 05, 2023; Accepted: January 21, 2023)

ABSTRACT

Spot-billed Pelican (*Pelecanus philippensis)* is a near-threatened bird found only in South and Southeast Asia. Colombo, the commercial capital of Sri Lanka, holds a naturalized population of *P. philippensis* released from captive collections of the National Zoological Gardens, Dehiwala. This study was conducted to investigate the distribution of *P. philippensis* and assess its population size in the Colombo district. We measured environmental variables and counted the number of birds foraging in all the water bodies with surface area >0.05Km^2. The rest of the water bodies were also observed to record the presence of pelicans. A roosting count of pelicans was conducted from April to December 2020 to assess their population size. *P. philippensis* was distributed in 14 lentic water bodies within the Colombo district and its minimum estimated population size was 193 individuals. Land-use patterns around the water body did not significantly impact (P>0.05) the distribution of pelicans. They were not recorded in water bodies with more than 10% vegetation cover. The abundance of *P. philippensis* in foraging sites was positively related to the chlorophyll-a content of the water (P<0.05). As it is the flagship faunal species in Colombo, its conservation needs immediate action from relevant authorities.

Keywords: Spot-billed Pelican, Abundance, Urban, Water bodies, Environmental variables

INTRODUCTION

Pelecanus philippensis (Gmelin, 1789), the spot-billed pelican, is a member of the Pelicanidae family, which includes eight living pelican species. This pelican was once common over much of Asia, including China, Pakistan, India, Nepal, Bangladesh, Sri Lanka, Myanmar, Vietnam, Laos, Thailand, Malaysia, Cambodia, Philippines, and Indonesia, with unconfirmed reports from Maldives, Hong Kong, Taiwan and Singapore (Crivelli & Schreiber, 1984; Stattersfield & Capper, 2000; Birdlife International, 2001; DENR, 2005; Li et al. 2006; Kannan et al. 2008; Gokula, 2011; Kannan & Jeganathan, 2016; Shankar et al. 2019). The current global population of *P. philippensis* is estimated to be 13,000-18,000 individuals and IUCN categorized this species as near threatened because its small population is continued to be declined (BirdLife International, 2017). The only known present-day breeding populations of *P. philippensis* occur in India, Sri Lanka and Cambodia and small numbers in Sumatra and Indonesia (Kannan & Manakadan, 2005; Bellio, Kingsford & Kotagama, 2009; Gokula, 2011; Birdlife International, 2017; Shankar et al. 2019). Kannan (2019) even proposed captive rearing as a conservation strategy because pelicans are extremely sensitive to environmental pollutants and face extinction in the wild.

In Sri Lanka, *P. philippensis* has been found naturally in coastal lagoons, large and small irrigation tanks and salt ponds in the dry zone (Bellio et al. 2009) for hundreds of years. However, the wet zone (Colombo) population was recently established after they escaped from the national zoological garden (NZG), Dehiwala, around the 1970s. The total population *P. philippensis* in Sri Lanka was around 5,000, perhaps overlapping with Sothern Indian population and the estimated breeding population size was fewer than 1000 pairs (Birdlife International, 2001). According to Kannan (2019), the estimated population of pelicans in southern India is almost 2850-3700. In order to introduce conservation measures, more recent data is needed on the population size and distribution of *P. philippensis* in Asia.

Even though their population is slowly declining in other parts of the world, the accidentally introduced *P. philippensis* has thrived for more than 50 years in the highly urbanized areas in the Colombo district. Irrespective of its importance for urban wildlife and its declining numbers in other parts of the world, no systematic study has been conducted to assess the population size and distribution of *P. philippensis* in the Colombo district. Therefore, this study aimed to investigate the environmental factors that affect the distribution and abundance, estimate the population size, and map the distribution of *P. philippensis* in the Colombo district in the wet zone, Sri Lanka.

MATERIALS AND METHODS

Study area:

The present study was conducted in the Colombo district ($6^0 75^{'}$- $6^0 94^{'}$ N, $79^0 82^{'}$- $79^0 94^{'}$ E) in the western province of Sri Lanka. Colombo is the most highly populated district in Sri Lanka and the commercial capital. Colombo district has mild weather conditions with a

*Corresponding Author's E-mail: epa@kln.ac.lk

temperature range of 22-31^{0}C. The annual rainfall is about 2400mm and heavy rains are recorded in monsoon seasons from March to August and October to January. From the Colombo district, 15 perennial water bodies greater than 0.05km^2 in size were selected as the study sites (Figure 1). In addition, the rest of the lentic water bodies found in the Colombo district were observed for the species presence. If present, the numbers were counted and considered in preparing the distribution map.

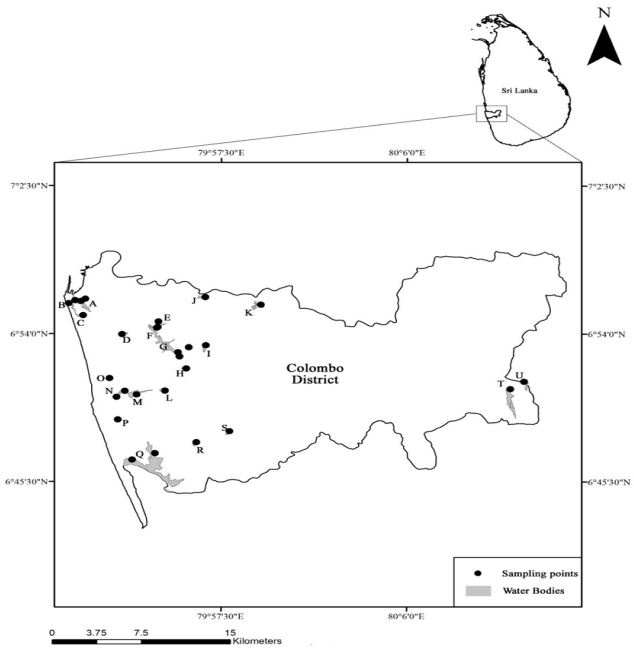

Figure 1. Map of the Colombo district showing selected study sites; A-Beira Lake-main, B-Beira-Gall face Lake, C-Beira-Gangarama Lake, D-Diyawanna Lake 1 (Heen ela marsh), E-Diyawanna Lake 2 (Kotuwegoda), F-Diyawanna Lake 3 (Water's Edge), G-Diyawanna Lake 4 (main), H-Diyawanna Lake 5 (Kimbulawala marsh), I-Thalangama Tank, J-Ambatale Tank, K-Kaduwela marshes, L-Boralesgamuwa Lake, M-Bellanwila park, N-Attidiya Lake, O-Rock pool-NZG, P-Kandawala Lake, Q-Bolgoda Lake, R-Kesbewa Lake, S-Olupattawa Lake, T-Labugama Reservoir, U-Kalatuwawa Reservoir

Field survey of *P. philippensis*:

The selected water bodies were visited on five occasions at equal intervals from April to December 2020. The total number of individuals in each water body was counted directly (Urfi, 2003; Kannan & Pandiyan, 2012) using Opticron 8x30 binoculars. For large water bodies, more than one observation point was used (to cover the whole water body visually) to ensure a complete estimate of birds. Care was taken to prevent double counts of individuals at the same or adjacent observation points. During the five sampling sessions, each site was visited according to a predetermined time sequence (i.e., 07:00-09:00hr, 09:00-11:00hr, 11:00-13:00hr, 13:00-15:00hr and 15:00-17:00hr) that would avoid any temporal biases in detection rates.

The locations of all roosting sites of *P. philippensis* within the Colombo district were first recorded using published literature and the information gathered from expert ornithologists, birdwatchers and local people. The roosting counts were taken to estimate the population size of *P. philippensis* (Kannan & Pandiyan, 2012). All sites were visited twice, morning (05:45- 06:15hr) and evening (17:45-18:30hr), to count the number of roosting individuals using a binocular (Opticron 8x30). The survey of *P. philippensis* at roosting sites was conducted for seven consecutive days starting from October 24, 2020, assuming that the individuals use the same location for roosting during the survey period. Maximum count was used for the statistical analysis (Kannan & Manakadan, 2005; Kannan & Pandiyan, 2016).

Environmental parameters of selected water bodies:

Chlorophyll-a content in water was measured according to APHA (1999) using a visible spectrophotometer (CECIL/Model: CE 1011, 1000 series). Water pH, salinity, conductivity, total dissolved solids (TDS) and dissolved oxygen (DO) of water were measured *in situ* at each selected water body using a calibrated multi-parameter (HACH/Model: Hq40d multi- parameter). The sizes of the water bodies were determined using digital maps (1:10000) obtained from the Survey Department, Sri Lanka. The surface area of water bodies covered with nonwoody macrophytes such as *Eichhornia* (Pontederiaceae) and *Nymphaea* (Nymphaeaceae) was calculated using the supervised image classification method in ArcGIS 10.2.2 software. The proportion of each land-use type within a 100m buffer around the water body was calculated using the same software. The GPS coordinates of the roosting sites were recorded using a handheld GPS (Etrex/ Model: Garmin summit). These coordinates were used to calculate the distance to roosting sites from each water body, thereby identifying the location closest to each.

***Data analysis**:*

During data analysis, the distance to the closest roosting site was taken as the minimum distance to a roosting site. The distribution map for *P. philippensis* in the Colombo district was created using ArcGIS 10.2.2 software (SL_grid_99 coordinate system) using coordinates of the water bodies in which *P. philippensis* occupied. The average number of *P. philippensis* in all water bodies was subjected to one-way ANOVA, followed by Tukey's pairwise comparison test. Before this, the data were subjected to Anderson- Darling Normality test to confirm the normality. The Simple linear regression analysis was performed between the average number of individuals of *P. philippensis* in each water body as the dependent variable and the environmental parameters of the water body as the independent variables separately. The Principal Component Analysis (PCA) was carried out to ordinate water bodies according to water quality parameters (pH, conductivity, salinity, TDS, DO) and surrounded land use percentages (i.e., % of homestead gardens, % of marshes, % of hydra (land uses contained water), % of parks, % of cultivations, % of scrublands, % of barren lands). Environmental variables except pH were transformed [($\log_{10}$ (x+1)] before the analysis. The relationship with the scores of environmental variables generated for the PC1 and PC2 axis in PCA analysis and the average number of individuals of *P. philippensis* were tested separately using regression analysis. All statistical analyses were performed at α=0.05 level using MINITAB 14.0 and Primer 5.0 software packages.

RESULTS

Abundance:

The number of *P. philippensis* recorded (Table 1) significantly varied among different water bodies

(One-way ANOVA, Tukey's test, $p<0.05$) in the Colombo district. The highest number of *P. philippensis* was recorded from the Rock Pool at NZG, Dehiwala (68, SE= 21). The second highest number of pelicans was recorded from Beira Lake-Main (38, SE=8 individuals). In contrast, *P. philippensis* was not recorded from Thalangama tank, Ambatale tank, Bellanwila park, Kesbewa Lake, Olupattawa Lake, Labugama and Kalatuwawa reservoirs. The number of pelicans recorded in Diyawanna Lake-2, Diyawanna Lake-3, Diyawanna Lake-5, Boralesgamuwa Lake and Attidiya Lake ranged between 1-3 birds.

Values with different superscripts denote a significant difference at a 95 % confidence level (one-way ANOVA, followed by Tukey's pairwise comparison test).

Table 1. Number of *P. philippensis* observed in different water bodies in the Colombo District

Water body	Name of the body	Number of *P. philippensis* (Mean ± SE)
A	Beira Lake- main	38 ± 8^{ab}
B	Beira- Galle face Lake	25 ± 1^{bc}
C	Beira-Gangarama Lake	16 ± 11^{bc}
D	Diyawanna Lake-1	11 ± 2^{bc}
E	Diyawanna Lake-2	1 ± 1^{c}
F	Diyawanna Lake-3	2 ± 1^{c}
G	Diyawanna Lake-4	11 ± 2^{bc}
H	Diyawanna Lake-5	3 ± 1^{bc}
I	Thalangama Tank	0
J	Ambatale Lake	0
K	Kaduwela marshes	11 ± 9^{bc}
L	Boralesgamuwa Lake	1 ± 0^{c}
M	Bellanwila park	0
N	Attidiya Lake	1 ± 1^{c}
O	Rock Pool-NZG	68 ± 21^{a}
P	Kandawala Lake	7 ± 3^{bc}
Q	Bolgoda Lake	8 ± 4^{bc}
R	Kesbewa Lake	0
S	Olupattawa Lake	0
T	Labugama Reservoir	0
U	Kalatuwawa Reservoir	0

Distribution:

P. philippensis was distributed in 14 lentic water bodies in the Colombo district. The distance from Dehiwala, NZG (where the *P. philippensis* was first released into the Colombo district) to the farthest lentic water body (R -Kesbewa Lake) occupied by *P. philippensis* was found to be 15Km (Figure 2).

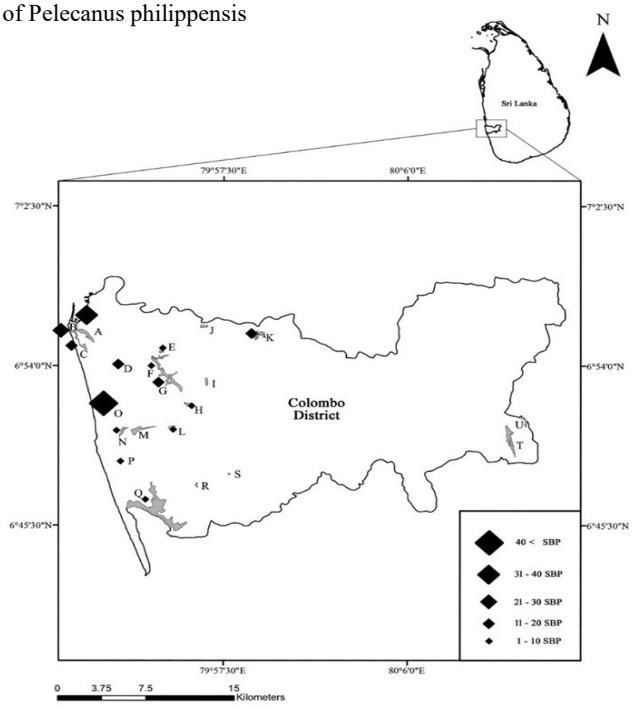

Figure 2. Distribution map of *P. philippensis* in the Colombo district, Sri Lanka

Chlorophyll-a and vegetation cover:

The chlorophyll-a content was significantly varied among different water bodies (ANOVA, Tukey's test, $p<0.05$) (Table 2). The highest mean chlorophyll-a content was recorded from the Beira main Lake (109.10, SE= 24.30mgm^{-3}), whereas the lowest value was recorded from the Diyawanna Lake-5 (Kimbulawala marsh) (2.64, SE= 0.53mgm^{-3}). The average number of *P. philippensis* recorded during the survey had a positive, significant relationship with chlorophyll-a content of water bodies (Figure 3) (Regression analysis, $p<0.05$).

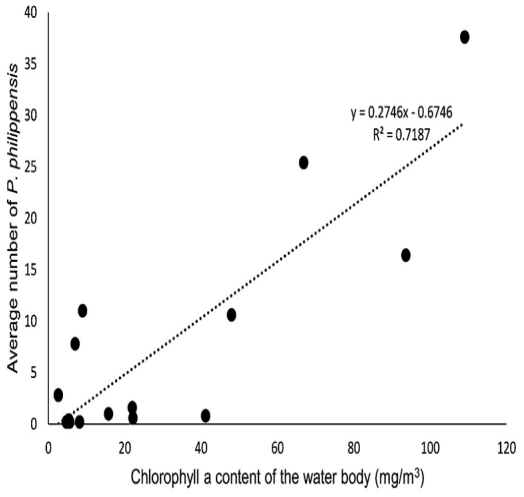

Figure 3. The relationship between the abundance of *P. philippensis* and chlorophyll-a content in different water bodies in the Colombo district, Sri Lanka.

Table 2. The chlorophyll-a content and % percentage vegetation cover of 15 selected water bodies and the minimum distance to the nearest roosting site of *P. philippensis*

Water body	Chlorophyll-a content (mgm^{-3}) (Mean ± SE)	% Surface vegetation cover	Minimum distance to a roosting site (km)
Beira Lake-main	109.1 ± 24.30^{a}	0.00	0.00
Beira- Galle face Lake	66.9 ± 33.40^{abc}	0.00	0.80
Beira-Gangarama Lake	93.7 ± 38.00^{ab}	0.00	0.00
Diyawanna Lake-1	48.0 ± 20.90^{abc}	7.66	0.00
Diyawanna Lake-2	**15.8 ± 5.42^{bc}**	**0.00**	**3.10**
Diyawanna Lake-3	21.9 ± 8.35^{bc}	0.00	2.77
Diyawanna Lake-4	9.0 ± 2.44^{bc}	0.00	0.00
Diyawanna Lake-5	2.6 ± 0.53^{bc}	3.13	0.00
Thalangama Tank	5.4 ± 1.32^{bc}	60.10	2.28
Ambatale Lake	5.6 ± 0.98^{bc}	24.96	6.16
Boralesgamuwa Lake	41.2 ± 10.9^{c}	16.53	2.26
Bellanwila park	8.2 ± 2.61^{bc}	1.50	2.26
Attidiya Lake	22.2 ± 10.1^{bc}	0.00	1.95
Bolgoda Lake	7.0 ± 1.63^{bc}	5.75	8.86
Kesbewa Lake	4.7 ± 0.63^{bc}	34.93	9.91

Chlorophyll-a values with different superscripts denote a significant difference at a 95 % confidence level (one-way ANOVA, Tukey's test).

According to the results, the Thalangama tank had the highest surface vegetation cover (60.1%). Seven lentic water bodies, including Beira main Lake, Beira Galleface Lake, Beira Gangarama Lake, Diyawanna Lake-2, Diyawanna Lake-3, Diyawanna Lake-4 and Attidiya Lake did not contain any surface vegetation (Table 2) during the sampling period. The surface vegetation cover of the water body negatively related to the abundance of *P. philippensis* (Figure 4) though the relationship was not significant according to regression analysis ($p>0.05$). *P. philippensis* did not occupy water bodies covered by more than 10% surface vegetation.

Size and land use pattern around water bodies: The size of the water body did not relate to the abundance of pelicans (Regression analysis, $p>0.05$) in the Colombo district (Figure 5).

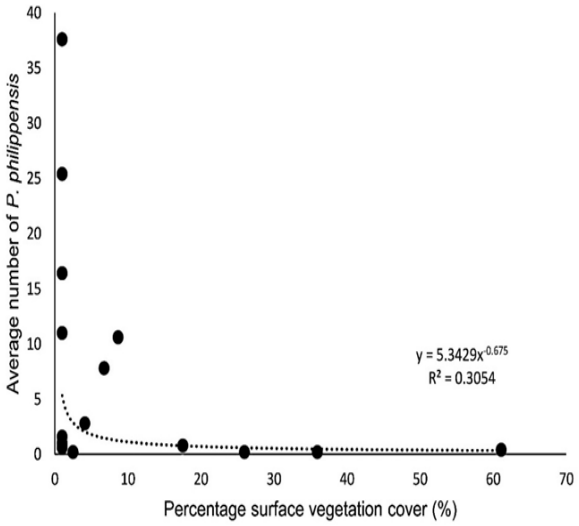

Figure 4. The relationship between the average number of *P. philippensis* recorded in different water bodies and the percentage of surface vegetation cover in the Colombo district, Sri Lanka

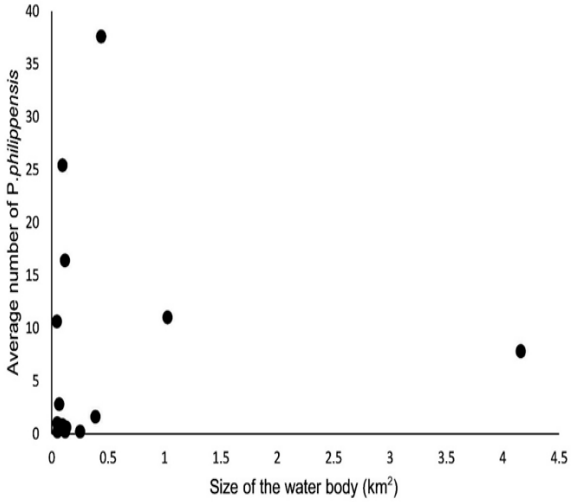

Figure 5. Scatter plot of the mean number of *P. philippensis* recorded against the size of 15 water bodies

Most of the selected water bodies were surrounded by human settlements and scrublands (Table 3). Out of 15 selected water bodies, nine were mainly surrounded by homestead land use (>75%). Beira Lake-Galleface was surrounded primarily by sea (71.61%). In comparison, more than 50% of the land area of Diyawanna Lake-5 (Kimbulawala marsh), Bellanwila Park and Attidiya Lake were surrounded by cultivations, mainly paddy fields. The highest percentage of scrublands, marshes and barren lands were found around Diyawannawa Lake-1 (Heen ela marsh) (16.39%) and Diyawanna Lake-2 (Kotuwegoda) (23.43%), respectively.

Table 3. Percentage land use pattern around 15 selected water bodies

Water body	Size (Km^2)	Land use %							
		HS	SL	M	BL	P	H	C	PG
Beira Lake-main	0.44	98.87	0.00	0.08	0.00	0.00	0.64	0.00	0.41
Beira-Galle face Lake	0.10	26.67	0.00	0.00	0.10	0.00	71.61	0.00	0.04
Beira-Gangarama Lake	0.12	94.50	0.00	3.79	0.45	0.00	0.00	0.00	1.26
Diyawanna Lake-1	0.05	71.17	16.39	12.02	0.43	0.00	0.00	0.00	0.00
Diyawanna Lake-2	0.05	66.48	0.00	23.43	7.67	0.00	2.42	0.00	0.00
Diyawanna Lake-3	0.39	57.45	14.81	7.83	3.01	2.24	14.65	0.00	0.00
Diyawanna Lake-4	1.03	40.78	4.83	14.99	7.77	3.15	27.47	0.67	0.00
Diyawanna Lake-5	0.07	35.66	0.00	6.24	2.35	0.00	1.54	54.21	0.00
Thalangama Tank	0.10	77.13	1.26	0.86	1.16	0.00	3.7	15.58	0.00
Ambatale Lake	0.12	84.65	1.78	10.69	0.08	0.00	2.53	0.27	0.00
Boralesgamuwa Lake	0.10	96.17	0.18	0.37	0.00	0.00	0.00	3.28	0.00
Bellanwila park	0.25	47.16	0.00	0.00	0.00	0.00	0.00	52.84	0.00
Attidiya Lake	0.13	47.41	0.00	0.00	0.00	0.00	0.00	52.59	0.00
Bolgoda Lake	4.16	81.93	6.45	2.32	0.49	0.00	2.08	6.33	0.40
Kesbewa Lake	0.05	87.43	11.51	0.85	0.00	0.00	0.00	0.00	10.9

HS = Homestead; SL = Scrublands; M = Marshes; BL = Barren lands; P = Parks; H = Hydra; C = Cultivations; PG = Playground

PCA performed for eight land use patterns allowed us to identify two components that explain 58% of the total variance. However, according to the regression analysis, there is no relationship between the number of individuals of *P. philippensis* and the land use pattern around water bodies (Regression analysis, $p>0.05$) (Figs. 6 & 7).

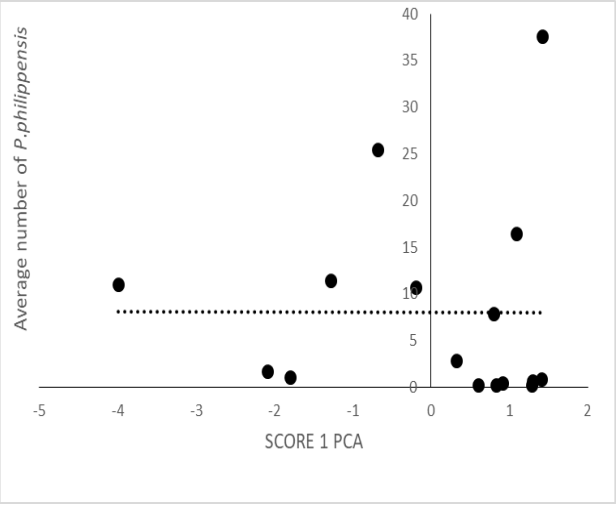

Figure 6. Scatter plot of the mean number of *P. p*hilippensis recorded in different water bodies against the first PC axis score from the PCA for land use percentages

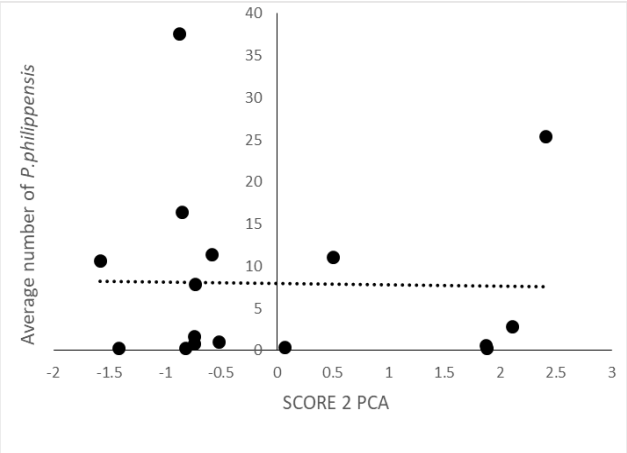

Figure 7. Scatter plot of the mean number of individuals of *P. philippensis* recorded in different water bodies against the second PC axis score from the PCA for land use percentages

Distance to the nearest roosting site:

Kesbewa Lake had the highest distance (9.91 km) from the foraging site to the nearest roosting site of *P. philippensis*. This distance for Beira-main Lake, Beira-Gangarama Lake, Diyawanna Lake-1, Diyawanna Lake -4 and Diyawanna Lake-5 were recorded as zero as the roosting sites were located within or at the bank of the water body (Table 3). The number of *P. philippensis* showed a significant negative power function (Figure 8) with the distance to the nearest roosting site (Regression analysis, $p>0.05$).

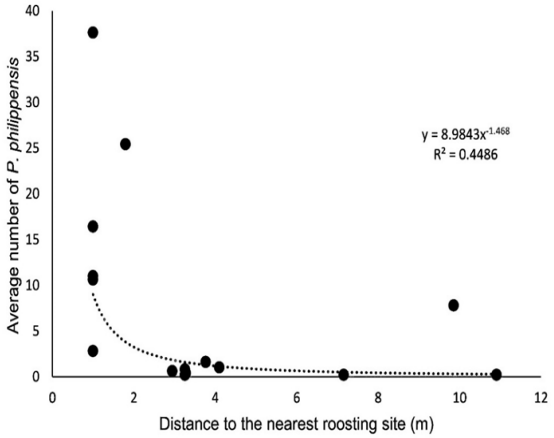

Figure 8. Scatter plot with regression line of the average number of *P. philippensis* recorded at 15 water bodies against the distance to the roosting site

Roosting count and nesting:

Ten roosting sites were observed within the Colombo district (Table 4), where the highest number of roosting birds (63) was recorded in NZG. According to the roosting counts, the minimum number of *P. philippensis* in the Colombo district was 193 individuals (Table 3). Three nesting sites identified during the study period were located at highly commercialized Dowson (N $6^0$55' E 79 ^{0}51') and Vauxhall (N 6 ^{0}92', E 79 ^{0}85') streets in Colombo city. *P. philippensis* used *Ficus bengalensis* (Moraceae) and *Pisonia grandis* (Nyctaginaceae) trees as nesting sites. The nest building was started in the third week of December, using small branches, sometimes with fresh leaves, as nesting materials.

Table 4. Number of P. philippensis recorded from 10 roosting sites found in Colombo District

Roosting site	GPS location	Number of *P. philippensis*
Streetlamp posts, Floating market, Fort	$6^0$93'32" N and 79^{0}85'44" E	4
Trees, Olcott Street, Fort	$6^0$93'11 N and 79^{0}84'43" E	24
Streetlamp posts, D.R. Wijayawardana Street	$6^0$93'22" N and 79^0 84'83" E	9
Trees, Beira Lake-main bank	$6^0$92'91" N and 79^{0}85'15" E	15
Trees, Vauxhall Street	$6^0$92'34" N and 79^{0}85'45" E	22
Trees, Beira Gangarama Lake bank	$6^0$91'62" N and 79^{0}85'33" E	21
Trees inside the Beira Lake	$6^0$90'01" N and 79^{0}88'25" E	12
Trees at Diyawanna Lake	$6^0$87'83" N and 79^{0}92'73" E	20
Trees, Rock pool, NZG	$6^0$85'72" N and 79^{0}87'32" E	63
Tree, Dehiwala	$6^0$86'34" N and 7^{0}986'61" E	3
Total		**193**

Table 5. Water quality parameters (mean±SE) of 15 selected water bodies

Water body	Water quality parameters				
	pH	Conductivity (µs/cm)	Salinity ‰	TDS (mg/l)	DO (mg/l)
Beira Lake-main	8.3±0.34^a	308.6±52.40^b	0.2±0.03^a	148.2±25.6^b	9.7±2.01^a
Beira-Galle face Lake	8.0±0.34^a	343.0±33.00^b	5.0±3.48^b	174.0±164^b	6.0±1.46^a
Beira-Gangarama Lake	8.0±0.74^a	274.1±52.70^b	0.1±0.03^a	130.8±25.6^b	7.0±2.32^a
Diyawanna Lake-1	6.8±0.16^a	421.0±105.00^b	0.2±0.05^a	203.1±51.4^b	3.7±2.04^a
Diyawanna Lake-2	7.5±0.63^a	239.8±11.60^b	0.1±0.01^a	114.2±5.47^b	9.0±1.21^a
Diyawanna Lake33	7.2±0.34^a	274.9±85.90^b	0.1±0.04^a	131.9±42.1^b	6.5±0.16^a
Diyawanna Lake44	7.3±0.26^a	194.1 ± 9.82^b	0.1±0.00^a	95.5±3.58^b	8.7±1.34^a
Diyawanna Lake-5	7.6±0.59^a	139.0±25.60^b	0.1±0.01^a	69.7±10.3^b	7.0±2.79^a
Thalangama Tank	6.1±0.31^a	124.5±12.10^b	0.1±0.01^a	56.6±5.86^b	2.7±0.68^a
Ambatale Lake	7.1±0.36^a	141.9±4.10^b	0.1±0.01^a	68.3±6.33^b	4.8±1.32^a
Boralesgamuwa Lake	7.8±0.59^a	198.1±8.99^b	0.1±0.00^a	71.3±19.8^b	9.6±1.39^a
Bellanwila park	7.4±0.43^a	257.6±30.80^b	0.1±0.01^a	122.9±15.0^b	4.9±1.16^a
Attidiya Lake	7.5±0.25^a	285.4±35.90^b	0.1±0.02^a	136.9±17.6^b	7.5±2.66^a
Bolgoda Lake	7.4±0.32^a	11506.0±7641.00^a	7.0±4.75^b	6788.0±4615^a	4.9±0.77^a
Kesbewa Lake	7.1±0.25^a	147.3±9.48^b	0.1±0.01^a	71.1±4.64^b	6.4±0.17^a

Values with different superscripts denote a significant difference at a 95 % confidence level (ANOVA, Tukey's test)

Water quality parameters:

The values were recorded from the Beira-main Lake (Table 5) highest pH (8.31, SE= 0.34) and DO (9.71, SE=2.01mgL^{-1}) whereas the lowest pH (6.08, SE=0.31) and DO 2.72, SE=0.68mgL^{-1}) values were recorded from the Thalangama tank. There were no significant differences among pH and DO values of different water bodies (ANOVA, Tukey's test, $p>0.05$). Significantly higher salinity levels were recorded from Bolgoda Lake

(7.01, SE=4.75‰) and Beira-Galleface (5.04, SE=3.48‰), while all other water bodies contained freshwater with a narrow salinity range of 0.06-0.15‰. Bolgoda Lake had significantly higher conductivity (11506, SE=7641µscm^{-1}) and TDS (6788, SE=4615mgl^{-1}) compared to all the other water bodies (ANOVA, Tukey's test, $p<0.05$) while Thalangama tank had the lowest conductivity (124.5, SE=12.1µscm^{-1}) and TDS (56.6, SE= 5.86mgl^{-1}).

PCA performed for five water quality parameters allowed us to identify two components that explain almost 90% of the total variance. According to Figure 9, the number of *P. philippensis* has a negative relationship that is not significant, with the score 1 representing conductivity, salinity and TDS of the water body (Regression analysis, $p>0.05$). The relationship between the number of *P. philippensis* and the score 2, which represents the pH and DO, was positive and according to simple linear regression analysis, the relationship was not significant (Regression analysis, $p>0.05$) (Figure 10).

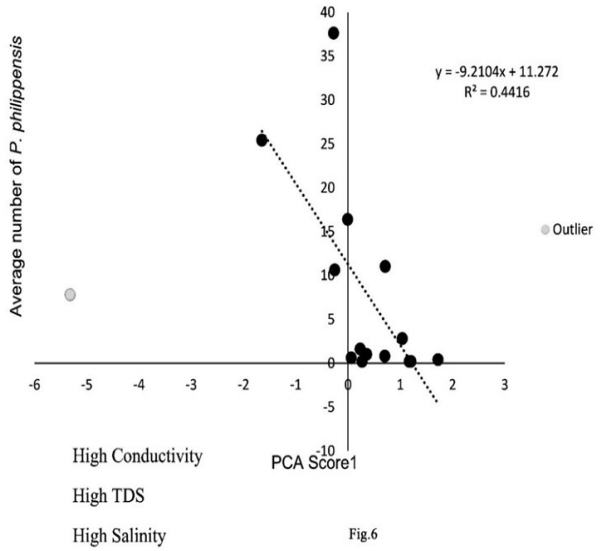

Figure 9. Scatter plot with regression line of the average number of individuals of *P. philippensis* recorded at 15 water bodies against the first PC axis score from the PCA for water quality parameters

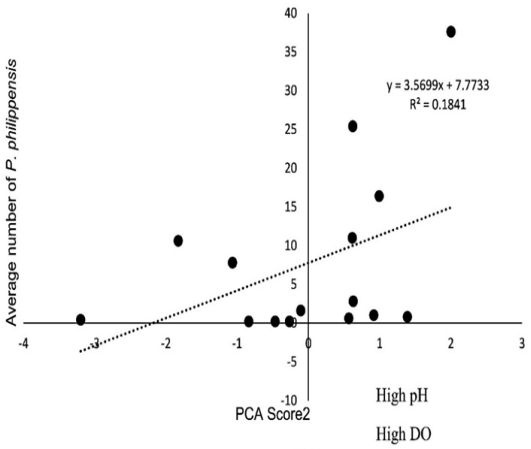

Figure 10. Scatter plot with regression line of the average number of *P. philippensis* recorded at 15 water bodies against the second PC axis score from the PCA for water quality parameters

DISCUSSION

This was the first study to investigate the factors affecting the population distribution of *P. philippensis* in highly urbanized Colombo, Sri Lanka, making a valuable contribution to the knowledge of urban biodiversity in Asia. The trophic status is considered a major factor influencing bird abundance and species richness in lakes (Hoyer & Canfield, 1994). According to the results of the present study, the abundance of *P. philippensis* in Colombo was significantly and positively related to the chlorophyll-a content of the water body. The abundance of bird populations in Florida Lakes also showed a positive relationship with the chlorophyll content in the water (Hoyer & Canfield, 1990). According to previous studies, chlorophyll content which is a direct measurement of primary production in aquatic ecosystems, has a positive relationship with the abundance of fish (Brown et al. 2000; Gomes, Miranda & Agostinho, 2002). Lentic water bodies in the Colombo district are not subjected to heavy fishing activities, making the fish available for piscivorous birds such as *P. philippensis.* Therefore, the abundance of *P. philippensis* could be positively related to the abundance of fish in its foraging sites in the Colombo district. The high abundance of bird species in urban areas where their food is readily available has been observed by Anderson et al. (1980), Anderson & Gress (1983 & 1984) and Donatelli et al. (2017).

Notably, *P. philippensis* distributed in the Colombo district did not occupy the water bodies with more than 10% surface vegetation cover. The abundance of birds decreased with the increase of surface vegetation cover of their foraging sites. Similar behavior of *P. philippensis* living around Pulicat Lake, India was observed by Kannan et al. (2008). Aquatic birds which feed upon plants or small invertebrates are associated with conditions of high plant biomass (Lillie & Evrard, 1994; Hoyer et al. 2006; Bellio et al. 2009). However, the fish eaters such as cormorants, goosanders and pelicans were most abundant when the plant biomass was low since the dense vegetation reduced the availability of foraging area for the birds and surface vegetation act as a mechanical barrier for their feeding (Milberg et al. 2001; Kumar & Gupta, 2009). This can be further affirmed, by the nesting failure of *P. philippensis* in 1994, due to the dense cover of water hyacinth (*Eichhornia crassipes*) in the wetlands of Kaziranga National Park, India. However, pelicans are considered 100% generalist regarding habitat preference. They have been recorded from various habitats, including deep water, shallow water, mudflats, exposed mudflats and temporal lakes (Rioja-Paradela, Carrillo-Reyes & Espinoza-Medinilla, 2014) in other parts of the world.

According to the results, land-use patterns surrounding the water bodies did not significantly impact the distribution of *P. philippensis* in the Colombo district, Sri Lanka. They were observed in water bodies surrounded by homestead gardens, cultivations, scrublands, playgrounds, marshes, barren lands and highly urbanized areas. *P. philippensis* may have adapted well to survive in habitats impacted by anthropogenic activities. This contrasts with Pearson (1993) and Kumar & Gupta (2009), who indicated that aquatic birds less preferred wetlands subjected to

human disturbances. The behavioral, physiological and ecological flexibility of pelicans indicated by Bonier, Martin & Wingfield (2007) may have contributed to its ability to tolerate a broad range of environmental conditions, including disturbed, urbanized habitats. However, populations of *P. philippensis* found in the country's dry zone avoid areas with human disturbances. In rural areas, *P. philippensis* are largely hunted but are not hunted in highly urbanized areas providing them additional protection from their natural predators (Kannan & Pandian, 2016). Though the wetland's size is often considered a crucial determinant of aquatic bird abundance (Hattori & Mae, 2001), such a relationship was not observed in the present study. Pelicans inhabited the water bodies with a size range from 0.05-4.16Km^2 and their numbers in those habitats ranged from 0-38 individuals. If there is sufficient food, small water bodies may be more advantageous for them because they must spend less effort on foraging.

Pelicans are colonial birds and prefer to live in groups by forming pelicanries. They usually proceed to a roosting site to spend the night as congregations (Bibby, Burgess & Hill, 2000; Gregory, Gibbons & Donald, 2004; Kannan & Pandiyan, 2016). Pelicans were found roosting in *Ficus bengalensis* (Moraceae) and *Pisonia grandis* (Nyctaginaceae) trees in the present study. At the same time, the population at Kokkare Bellur, India used *F. bengalensis*, *Albizia* (Fabaceae) and *Tamarindus indica* (Fabaceae) trees as roosting sites (Shankar et al., 2019). The abundance of *P. philippensis* inhabited the Colombo district had a significant negative power function with distance to their roosting sites. When roosting sites are closer, pelicans do not need to spend energy to fly long to find food, letting them save energy. According to Kannan & Pandiyan (2012), the availability of roosting sites nearby can even be considered a cause for pelicans' selection of foraging areas.

A total of 193 individuals from the roosting count can be taken as the minimum number of *P. philippensis* living in the Colombo district. The nest building of *P. philippensis* was started in the third week of December, but Jayawardana (2011) observed nest building during the first week of January. Considerable fluctuations in breeding seasons of *P. philippensis* (Gokula, 2011; Kannan & Pandiyan, 2016) and *P. occidentalis californicus* have previously been observed (Anderson et al., 1980; Anderson & Gress, 1983). *P. philippensis* used small branches and twigs as their nesting materials as observed in India by Gokula (2011). In general, they nest alongside other wetland birds such as Painted Storks, Lesser Adjutant and Asian Open bill (Birdlife International, 2001; Gokula, 2011; Taher, 2007), but such behavior of pelicans was not observed in the present study confirming the observations of Jayawardana (2011). Native bird species may be unable to tolerate landscape developments linked with urbanization, keeping the introduced pelicans alone in nesting sites in the Colombo district. As shown by the great white pelican (*Pelecanus onocrotalus*) at Blackpool Zoo, United Kingdom (Brereton et al. 2021), *P. philippensis* has not changed its overall behavior in the presence of humans in the Colombo district. The colonization success of *P. philippensis* in the Colombo district may have been attributed to the availability of the type of resources upon which pelicans depend, such as food, water, nesting and roosting sites and less predation. Moderate development in urbanized areas increases ornamental vegetation, water sources, primary productivity, and the amount of edge between habitats (Blair, 1996). *P. philippensis* may be an 'urban exploiter' that has the potential to adopt and exploit these changes.

Except for the rock pool of NZG, where zookeepers feed pelicans and other aquatic birds, the highest number of foraging pelicans was observed in Beira Lake, one of the most polluted eutrophic lakes in Sri Lanka. *P. philippensis* may mainly feed on introduced Tilapia species which survive under highly polluted conditions (McKaye et al., 1995) in Beira Lake. The dominancy of Nile tilapia (*Oreochromis niloticus*, Cichlidae) in Beira Lake and other aquatic ecosystems in the Colombo district has been documented by Pathiratne, Pathiratne & Seram (2010). Introduced European carp, *Cyprinus carpio carpio* (Cichlidae) was the major food item selected by *P. conspicillatus* populations in Coorong, South Australia (DENR, 2011). Fish populations in the Beira and Bolgoda Lakes in Sri Lanka are exposed to polycyclic aromatic hydrocarbons and toxigenic *Microcystis* blooms caused by anthropogenic activities (Pathiratne, Chandrasekara & Pathiratne, 2009; Pathiratne, Pathiratne & Seram, 2010). Pollutant-related direct mortalities and reproductive problems for *P. occidentalis* and *P. occidentalis californicus* have already been observed (Anderson & Gress, 1983; Crivelli & Schreiber, 1984). Pelican eggs had a high DDT concentration in the northeastern part of KwaZulu-Natal, South Africa, where DDT was used to combat malaria for several decades (Bouwman et al. 2019). In the northern Gulf of Mexico, pelicans had cadmium, mercury and selenium in their feathers (Ndu et al., 2020). Therefore, further research is warranted to study the potential impacts of feeding toxins-contaminated fish on the health of *P. philippensis* and other aquatic birds in Sri Lanka.

Due to the noise and lousy odor created by pelicanaries, several roosting and nesting trees have been removed by government authorities earlier in Colombo. Similarly, villagers in India also removed roosting and nesting sites, destroying several colonies of pelicans due to nuisance (Birdlife International, 2001; Taher, 2007; Kannan, 2019). *P. philippensis* is the only resident pelican species found in Sri Lanka and can be considered the top carnivore in most of the wetlands in Colombo, contributing to the balance of the aquatic food web. *P. philippensis* in the Colombo district have few alternatives if the removal of their roosting and nesting sites and degradation of their foraging sites will continue.

As it can be considered the flagship faunal species in Colombo, Sri Lanka, its conservation needs immediate action from relevant authorities.

ACKNOWLEDGMENTS

We thank Jagath Gunawardana, Uditha Hettige, Divanka Randula, Kalya Subasinghe, Gayashan M. Arachchige and Anoma Priyadarshani for supporting in numerous ways to conduct the study.

REFERENCES

American Public Health Association (APHA). 1999. *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, Washington, DC.

Anderson, D. W. and Gress, F. 1983. Status of a Northern population of California brown pelicans. *Condor* 85:79-88. https://doi.org/10.2307/1367894

Anderson, D. W. and Gress, F. 1984. Brown Pelicans and the anchovy fishery off southern California. *Marine birds: their feeding ecology and commercial fisheries relationship*, 128-135.

Anderson, D.W., Gress, F., Mais, K.F. and Kelly, P. R. 1980. Brown pelicans as anchovy stock indicators and their relationships to commercial fishing. *Calif. Coop. Oceanic Fish. Invest. Rep 21*, 54-61.

Bellio M.G., Kingsford R.T. and Kotagama, S.W. 2009. Natural versus artificial- wetlands and their waterbirds in Sri Lanka. *Biological Conservation, 142*, 3076–3085. https://doi.org/10.1016/j.biocon.2009.08.007

Bibby, C.J., Burgess, N.D. and Hill, D.A. 2000. *Bird census techniques*. 1st edition, Academic Press Limited, London.

BirdLife International. 2001. *Threatened birds of Asia: the BirdLife International Red Data Book.* Cambridge, UK: BirdLife International.

BirdLife International. 2017. *Pelecanus philippensis*. The IUCN Red List of Threatened Species 2017: e.T22697604A117970266.

Blair, R. B. 1996. Land Use and Avian Species Diversity along an urban gradient *Ecological Applications*, *6*(2) 506-519. https://doi.org/10.2307/2269387

Bonier, F., Martin, P. R. and Wingfield, J. C. 2007. Urban birds have broader environmental tolerance. *Biology letters*, *3*(6), 670-673. https://doi.org/10.1098/rsbl.2007.0349

Brereton, J.E., Fryer, J. and Rose, P.E., 2021. Understanding sociality and behavior change associated with a nesting event in a captive flock of great white pelicans. Zoo Biology, 40(5): 386-397. https://doi.org/10.1002/zoo.21616

Brown, C. D., Bachmann, R. W. Hoyer, M. V. and Canfield, D. E. 2000. Nutrient-chlorophyll relationships: an evaluation of empirical nutrient-chlorophyll models using Florida and north temperate Lake data. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 1574-1583. https://doi.org/10.1139/f00-090

Bouwman, H., Yohannes, Y.B., Nakayama, S.M.M., Motohira, K., Ishizuka, M., Humphries, M.S., van der Schyff, V., du Preez, M., Dinkelmann, A. and Ikenaka, Y. 2019. Evidence of impacts from DDT in pelican, cormorant, stork, and egret eggs from KwaZulu-Natal, South Africa. *Chemosphere,* 225: 647-658. https://doi.org/10.1016/j.chemosphere.2019.03.043

Crivelli, A. J. and Schreiber, R. W. 1984. *Biological Conservation*, Status of the Pelecanidae. 30 (2): 147-156.

Department of Environment and Natural Resources (DENR). 2005. Protected Areas and Wildlife Bureau. Philippine Wetlands in the South China Sea: Conservation Priorities. UNEP/GEF Project: Reversing Environmental Degradation Trends in the South China Sea and Gulf of Thailand. Quezon City, Philippines, 48 pp.

Department of Environment and Natural Resources (DENR). 2011. Breeding Australian pelican *Pelecanus conspicillatus*, in the Coorong, South Australia 2010-11. Department of Environment and Natural Resources, Adelaide. 27p.

Donatelli, R. J., Eaton, D. P., Sementili-Cardoso, G., Vianna, R. M., Gerotti, R. W., Rodrigues, F. G. and Martins, R. M. 2017. Temporal and spatial variation of richness and abundance of the community of birds in the Pantanal wetlands of Nhecolândia (Mato Grosso do Sul, Brazil). International Journal of Tropical Biology, ISSN-0034-7744) Vol. 65 (4): 1358-1380.

Gokula, V. 2011. Breeding biology of the Spot-billed Pelican (*Pelecanus philippensis*) in Karaivetti Bird Sanctuary, Tamil Nadu, India. *Chinese Birds*, *2*, 101-108. https://doi.org/10.5122/cbirds.2011.0013.

Gomes, L. C., Miranda, L. E. and Agostinho, A. A. 2002. Fishery yield relative to chlorophyll a in reservoirs of the Upper Paraná River, Brazil. *Fisheries Research*, *55*(1-3), 335-340. https://doi.org/10.1016/S0165-7836(01)00278-8

Gregory, R. D., Gibbons, D. W. and Donald, P. F. 2004. Bird Census and Survey Techniques, Bird Ecology and Conservation: A Handbook of Techniques. Oxford University Press, Oxford.

Hattori, A. and Mae, S. 2001. Habitat use and diversity of waterbirds in a coastal lagoon around Lake Biwa, Japan. *Ecological Research*, *16*(3), 543-553. https://doi.org/10.1046/j.1440-1703.2001.00416.x

Hoyer, M. V. and Canfield, D. E. 1990. Limnological Factors Influencing Bird Abundance and Species Richness on Florida Lakes. *Lake and Reservoir Management*, *6*(*2*), 133-141. https://doi.org/10.1080/07438149009354703

Hoyer, M. V. and Canfield, D. E. 1994. Bird abundance and species richness on Florida lakes: influence of trophic status, lake morphology, and aquatic macrophytes. *Hydrobiologia*, 297/280: 107-119. https://doi.org/10.1007/BF00027846

Hoyer, M. V., Notestein, S. K., Frazer, T. K. and Canfield, D. E. 2006. A comparison between aquatic birds of Lakes and coastal rivers in Florida. *Limnology and Aquatic Birds*, 5-18. https://doi.org/10.1007/s10750-006-0056-9

Jayawardena, S.P.M. 2011. Study of roosting & breeding behavior of *Pelecanus Philippensis* (Family Pelicanidae; Spot-billed Pelican) at one of the major roosting sites in Colombo, M.sc thesis, Faculty of Science, University of Colombo, Sri Lanka. Conservation of the Spot-billed Pelican Pelecanus philippensis in southern India

Kannan, V. 2019. Conservation of the Spot-billed Pelican *Pelecanus philippensis* in southern India. *International Journal of Zoology Studies*, 4(6): 01-10.

Kannan, V. and Jeganathan, P. 2016. Spatial and Temporal Variations of The Density of Spot-Billed Pelican *Pelecanus philippensis* in Pulicat Lake, East Coast of Southern India. *International Journal of Pure and Applied Zoology*, *4*(1).

Kannan, V. and Manakadan, R. 2005. The status and distribution of Spot-billed Pelican *Pelecanus philippensis* in southern India. *Forktail*, 21:9–14.

Kannan, V. and Manakadan, R. 2005. The status and distribution of Spot-billed Pelican Pelecanus philippensis in southern India. *Forktail*, *21*, p.9.

Kannan, V. and Pandiyan, J. 2012. Nesting ecology of the Spot-billed pelican Pelecanus philippensis in southern India. *World Journal of Zoology*, *7* (4), 295-302. https://doi.org/10.5829/idosi.wjz.2012.7.4.6519

Kannan, V., Manakadan, R. A. N. J. I. T., Rao, P. R. A. K. A. S. H., Mohapatra, K. K., Sivakumar, S. and Santharam, V. 2008. The waterbirds of Pulicat Lake, Andhra Pradesh–Tamil Nadu, India, including those of the adjoining wetlands and heronries. *J Bombay Nat Hist Soc*, *105*(2), 162-180.

Kumar, P. and Gupta, S. K. 2009. Diversity and abundance of wetland birds around Kurukshetra, India. *Our nature*, *7*(1), 212-217.

Li, Z.W.D., Yatim, S. H., Howes, J. and Ilias, R. 2006. Status Overview and Recommendations for the Conservation of Milky Stork Mycteria cinerea in Malaysia: Final Report of the 2004/2006 Milky Stork Field Surveys in the Matang Mangrove Forest, Perak, Malaysia. Wetlands International and the Department of Wildlife and National Parks, Peninsular Malaysia, Kuala Lumpur, Malaysia. 80p.

Lillie, R. A. and J. O. Evrard. 1994. Influence of macroinvertebrates and macrophytes on waterfowl utilization of wetlands in the Prairie Pothole Region of northwestern Wisconsin. *Hydrobiologia* 279/280: 235-246. https://doi.org/10.1007/BF00027857

McKaye, K.R., Ryan, J.D., Stauffer Jr, J.R., Perez, L.J.L., Vega, G.I. and van den Berghe, E.P. 1995. African tilapia in Lake Nicaragua. *BioScience*, pp.406-411. https://doi.org/10.2307/1312721

Milberg, P., Gezelius, L., Blindow, I., Nilsson, L. and Tyrberg, T. 2002. Submerged vegetation and the variation in the autumn waterfowl community at Lake Takern, southern Sweden. *Ornis Fennica*, *79*(2), 72-81.

Ndu, U., Lamb, J., Janssen, S. et al. Mercury, cadmium, copper, arsenic, and selenium measurements in the feathers of adult eastern brown pelicans (*Pelecanus occidentalis carolinensis*) and chicks in multiple breeding grounds in the northern Gulf of Mexico. 2020. Environment Monitoring and Assessment. 2020. 192: 286. https://doi.org/10.1007/s10661-020-8237-y

Pathiratne, A., Chandrasekera, L. W. H. U. and Pathiratne, K. A. S. 2009. Use of biomarkers in Nile tilapia (Oreochromis niloticus) to assess the impacts of pollution in Bolgoda Lake, an urban water body in Sri Lanka. *Environmental Monitoring and Assessment*, *156*(1-4), 361. https://doi.org/10.1007/s10661-008-0490-4

Pathiratne, A., Pathiratne, K. A. S. and De Seram, P. K. C. 2010. Assessment of biological effects of pollutants in a hypereutrophic tropical water body, Lake Beira, Sri Lanka using multiple biomarker responses of resident fish, Nile tilapia (Oreochromis niloticus). *Ecotoxicology*, *19*(6), 1019-1026. https://doi.org/10.1007/s10646-010-0483-2

Pearson, S. M. 1993. The spatial extent and relative influence of landscape-level factors on wintering bird populations. *Landscape Ecology*, *8*(1), 3-18. https://doi.org/10.1007/BF00129863

Rioja-Paradela, T., Carrillo-Reyes, A. and Espinoza-Medinilla, E. 2014. Effect of temporal lakes on avifaunal composition at the Southeast of Isthmus of Tehuantepec, Oaxaca, Mexico. International Journal of Tropical Biology ISSN-0034-7744) Vol. 62 (4): 1523-1533. https://doi.org/10.15517/rbt.v62i4.12994

Shankar, H. R. and Govindharajalu, M. 2019. Foraging behaviour of pelicans in Kokkare Bellur, Maddur, Karnataka, India. Pramana Research Journal. 9(5): 140-148.

Taher, H. 2007. The Spot-billed Pelican, *Pelecanus philippensis* of Uppalpaddu (Guntur) district, Andhra Pradesh, India. *Indian Birds*, *3*(1), 13-16.

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